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Development of a Guide to model existint buildings in BIM

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REPORT

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1. INTRODUCTION

1.1 Justification

The built area of public buildings in the Catalonian Region is composed in a 43% by educational facilities, which are responsible for approximately 7,53% of the public primary energy consumptions (Radulov et al. 2014). The management of this facilities usually relies on spread data which is often incomplete, and this situation difficulties the duties of the facility managers. Building Information Modelling (BIM) technology has recently revealed its potential as a tool to centralize information, to organize it in one unique source, to provide a reliable data-basis that will improve the maintenance of the building during its Operational and Maintenance phase (O&M).

Although BIM has been already implemented in new construction buildings, its application to existing buildings has not been developed. Implementing BIM in existing facilities has high potential considering that 42% of public buildings in the Catalonian Region were built before any energy public regulation for buildings existed (year 1981) (COMISSION 2017). In order to improve the maintenance of such buildings by means of the BIM technology, it's fundamental to have a method to model the current stock of these buildings. This master thesis will develop a standardized procedure to model existing buildings in BIM, specifically oriented to their Facility Management (FM). This method should define which data is needed in the model to enable FM, it should define how to organize it, and should also face the lack of digitalized or available data of the building at the starting point of the modelling process.

1.2 Aim

The aim of this work is to develop a guide that standardizes the procedure of modelling an existing building with BIM technology, specifically oriented to its FM.

1.3 Scope

The guide to be developed in this master thesis will embrace all the services that get involved in the FM of one public educational equipment. Then the guide will be implemented to model the GAIA building at UPC campus Terrassa.

It will not be applicable to other types of facilities such as residential buildings, single houses or hospitals, as the equipment considered in the modelling corresponds to that of an educational building.

1.4 Requirements

This master thesis fulfils the following requirements:

- To be presented by October of 2017 as deadline of the studies MSc in Structural and Construction Engineering.
- To be developed in English: the corrections provided by the advisor and collaborator have been completely managed in this language.
- The feasibility of this guide is demonstrated by implementing it on a real case study: the Gaia building at UPC campus Terrassa.
- The software used for modelling the practical study is Autodesk Revit.
- This master thesis continues the work of Seuma (2016), which presented a draft study on modelling existing buildings in BIM.

1.5 Structure of the master thesis

This work is organized in the following chapters and their respective topics:

Introduction

The general aim of the research is explained. This chapter introduces the relevance of the case, the need to stablish a standardized procedure to model existing facilities in BIM in order to improve their FM activities.

State of the art

Based on literature review, this chapter explains the actual state of BIM and its applications to FM, pointing out the challenges to fulfil the aim of the work. It's organized in three parts that focus: first on the current state of BIM, then on the actual advances and lacks regarding its application to FM, and finally on the actual data sources of existing buildings.

Methodology

In this chapter are defined the steps to develop the guide that is aim of this work.

Guide for modelling existing buildings in BIM

The proposed guide is an improvement of the research "Study of the modelling process in BIM of an existing building in Campus Terrasa" (Seuma Areñas 2016), this improvement embraces aspects as the definition of data requirements, the classification system to organize them, and the centralization of this information.

Case study

This chapter faces the practical implementation of the guide, it develops the BIM modelling of Gaia building in UPC Terrasa campus.

Evaluation

Due to the lack of information, some data will be based on hypothesis. This chapter will study how realistic the model is, based on the percentage of real information that it contains at the end of the process.

Discussion and conclusions

The findings of the research are presented and further research is addressed.

2. STATE OF THE ART

Nowadays in the European Union, buildings rely their FM tasks on diverse source of systems. The data that is needed to address the maintenance of a building is spread along several sources, that usually mix automated systems with paper formats, such as schedules, product data sheets, etc. (Kassem 2015). This diaspora was exemplified in the study of a university campus. The different kind of data and systems used to manage the buildings of Terrassa Campus from UPC is illustrated on Table 1.

Table I. Kind of data and where is located.. Terrassa UPC Campus Case Study (Bortolini et al. 2015)

Kind of data	Example	Located
Building characteristics data	Type of material, age of equipment	Paper-based and Somdoc
Building monitoring and control data	Exterior Temperature, humidity	Informet
	Interior Temperature, boilers switch on/off	TAC
	Electrical, gas, water consumptions	Power Studio
Maintenance management data	Inventory, schedules, equipment's lifespan	Paper-based and Archibus
Space management data	Relocation of equipment	Archibus
	Day room reservation	School intranet

This sources are often inconsistent, and this derives in quite a lot of problems, as it complicates any management process that rely on this source of information. Without a reliable database as a decision making tool, is difficult to execute tasks such as up-dating data when the building gets refurbished, communicating information between the professionals involved in the management, or designing further maintenance plans.

In order to improve the management of the building, BIM technology allows to centralize all the information into one unique and reliable source. It allows to generate, store, manage, exchange and share building information in an interoperable and reusable way. (Vanlande et al. 2008)

Centralizing FM information in a BIM model can lead to several benefits. Among them is the possibility of improvement of the energetic behaviour of the building. BIM software can communicate with FM software (Volk et al. 2014), to control the installations by means of input and output data. The optimization of this installations could lead to a reduction on the consumptions of the building, therefore to a minimization of its cost and environmental footprint. Another benefit is that this model would allow to design an efficient maintenance plan, therefore to invest effectively in preventive maintenance rather than reactive maintenance. Reactive maintenance tends to cost 3-4 times more than preventive maintenance, so this is an interesting point for the owner considering that 60% of the total cost of ownership are incurred during O&M stage (Garrett et al. 2010). This benefit was pointed out by the National Research Council (NRC) in 1998, which reported that the main reason public buildings are deteriorating is the failure to recognize the total cost of ownership. Based on the savings that can be derived from reinforcing preventive maintenance, the information of the O&M stage should be considered as a capital investment by facility managers. Especially when analysing the owners return on investment (ROI) on such information (Mayo et al. 2012).

Although this is a potential benefit, the scope of this thesis does not embraces the energetic optimization of the building's consumptions.

2.1 Building Information Modelling: terms and definitions

To understand the vast field of BIM, section 2.1 addresses fundamental concepts that set the ground of this topic. They all are related with the concept of information: how to transmit it in a collaborative workflow, how to classify it, and the criteria to measure its content.

BIM technology is a field recently discovered and in continuous evolution, so there are terms which have been modified from the original definitions. In those cases, both the original as the up-dated versions are explained.

Building Information Modelling (BIM): the original BIM handbook describes it as the activity that embraces the tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation. (Eastman et al. 2008)

Generally, this concept covers the group of experts, tools, techniques and concepts that rely on the use of coordinated, coherent, computable and continuous information (Figure 1). This information should integer geometrical properties of a building and its components, along with their semantic attributes relevant for the specific use of the model, at a certain stage of the building's lifecycle. (Coloma 2010)

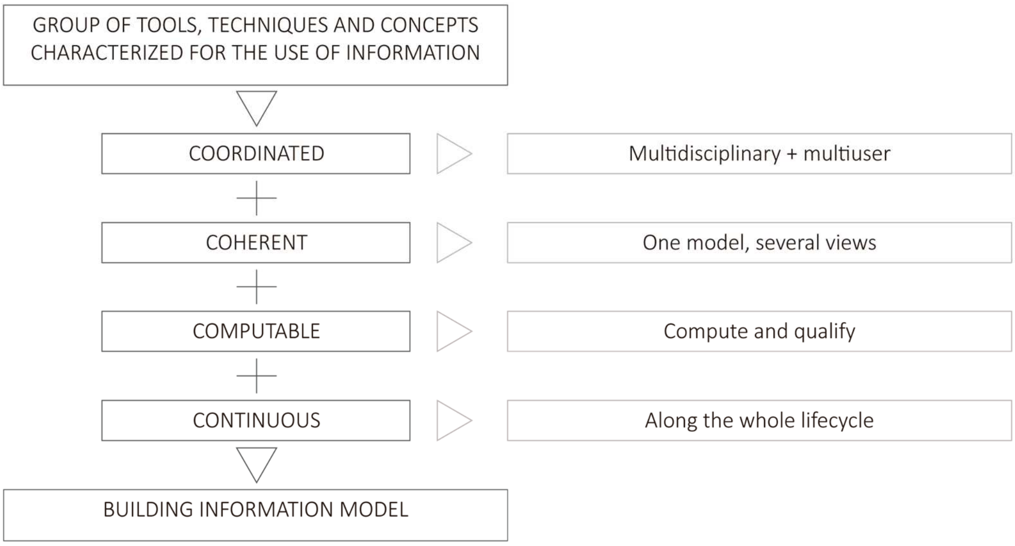


Figure 1. The use of the coordinated, coherent, computable and continuous information is the basis for BIM (Coloma 2010)

BIM application: the specific use of a building information model, to support a work process or work task by the project team (Eastman et al. 2008).

BIM authoring tool: a software application used to generate and manipulate building information models. The term can be further qualified to denote specific application areas. For example "BIM Design Tool" is often used to refer to tools used primarily for architectural design such as Revit Building, Bentley Architecture, Digital Project and ArchiCAD (BUILDING SMART Spanish Chapter 2014a).

IFC format: Industry Foundation Classes is a standardized file format, elaborated by the BuildingSmart Alliance (BSA), to facilitate the exchange of information between computer applications inside a BIM workflow (BUILDING SMART Spanish Chapter 2014b).

This file format is based on a common programming language. Depending on the software that generates an .ifc file, this file will have higher or lower level of interoperability inside BIM workflows. When a software has high IFC interoperability, it's recognized by awards as "openBIM" of BuildingSMART, or NBIMS. (Volk et al. 2014)

OmniClass Construction Classification System: is a classification system to organize the entire built environment. By assigning a specific code to each element of the built environment (based on its form, function, scale, etc), it provides a standardized basis for classifying information created and used by the architectural, engineering and construction (AEC) industry, throughout the full facility life cycle, from conception to demolition or reuse, and encompassing all of the different types of construction that make up the built environment. It's an open and extensible standard available to the AEC industry at large (C. 2006)

UniFormat II: standardized format for classifying building elements and related sitework (Charette & Marshall 1999). It provides a standard method for arranging construction information, organized around the physical parts of a facility called systems and assemblies. These systems and assemblies are characterized by their function without identifying the technical or design solutions that may compose them. (C. 2006)

COBie: the Construction Operations Building Information Exchange is a specification. It denotes how information may be captured during design and construction, and provided to facility operators. It eliminates the current process of transferring massive amounts of paper documents to facility operators after construction has been completed (Designer 2013).

LOD: the definition of this concept has been widely discussed and there is no a closed conclusion. Originally introduced by the American Institute of Architects (AIA) as an abbreviation for Level of Detail, the term LOD was changed in 2013 to represent Level of Development. LOD are the set of requirements for the concretization of both graphical and non-graphical information during a project. (Vestergaard & Karlshoj 2016)

Nevertheless, the LOD Specification distinguishes some differences between this two concepts. Level of Detail is how much detail is included in the model element. Level of Development is the degree to which the element's geometry and attached information has been thought through – the degree to which project team members may rely on the information when using the model (Forum 2015).

Level of information: requirements for non-graphical information. Such requirements are stated explicitly as object properties in some LOD concepts, and other described implicitly just as information needed to fulfil specific use cases. (Vestergaard & Karlshoj 2016)

Level of reliability: is the degree up to which the element can be used as part of a contractual agreement. The level of reliability of an element can be: expected, specified, final or as-build. (Vestergaard & Karlshoj 2016)

Level of completeness: it is the degree of concretization of the model element and the scope of included components. The combination of a description and an illustration defines each LOC. (Vestergaard & Karlshoj 2016)

Level of Realism: this indicator reflects the reliability of the model, how correct it is in respect to reality. To compute this indicator, this research proposes to rely on the concepts of: Parameter's Quality and Parameter's Relevance.

Parameter's Quality (PQ): This parameter evaluates how certain is a data, based on the source it was taken from. Data taken on the site will have the highest PQ, as they are absolutely certain, and data obtained from the Basic Project will have a low PQ, as it is not so reliable.

Relevance (R): in the computation of the Level of Realism of the overall model, this indicator adjust the influence that each data has, based on its influence in the facility management.

Revit Workset: A collection of elements in a model. In a collaborative environment, the authority to modify a certain workset can be temporarily given to a specialist. The grouping principle is left to the criteria of the modeller.

Revit Schedule: Inside a Revit file, a schedule is a table that lists the properties of a certain element. The user can customize the properties that are shown, and how they organize.

2.2 BIM for FM

The purpose of this chapter is to set the ground on the current state of BIM applied to FM. It will explain its regulations and guidelines, and the data sources of FM information to be introduced in BIM models.

BIM for FM is a field with short development of research, so it presents several social and technical challenges. From the social side, traditional relationships between contractors stablish that as facility managers get hired for specific periods of time –usually 3 to 5 years–, they're not expected to work as successors by one each other. They start from poorly handed-over data that needs to be completed each time. This lack of quality information workflow derives in unnecessary stipends of time and money, and further impoverishment of the effective decision capacity due to the lack of a reliable data-basis.

From the technical point of view, full interoperability between software has yet to be accomplished. The use of BIM and the inclusion of early planning of facilities in design stages now "necessitates standardized business processes, taxonomies and data architectures" (Mayo et al. 2012). There is not a fluent interoperability between technologies, neither between BIM software nor between Computer Aided Facility Management Systems (CAFM). This lack of standardization is due to the differences between the capabilities and requirements of each FM software platform, but is currently being improved based on their common programming language (IFC) and compatible information structure.

2.2.1 BIM modelling: regulations and guides

Several countries have developed different BIM regulations and guidelines, which rely on the IFC format as a universal support that guarantees the compatibility of the whole BIM community. From these countries, this chapter explains key examples and organizes them between those cases in which BIM is compulsory for publicly funded construction projects, and those in which its application is optional.

Inside the European Union, BIM technology is compulsory for publicly funded building projects in these countries: the UK, Netherlands, Denmark, Finland and Norway (Autodesk 2014). From these countries, "*the UK has become a world leader in the implementation of BIM due to its well-structured and managed BIM action plan*." (Cobuilder 2017), so the British regulation is furtherly explained. The National BIM Standard of the United States ® (NBIMS-US ™), is also relevant for this research, as it is more specific than European regulations regarding the application of BIM for FM.

In Spain, the application of BIM technology is still optative, it is expected to be compulsory from 2018 on, for construction projects with budget higher than 2M€ (ITeC 2017). Currently in Spain, the Spanish Chapter for SMART BUILDING has developed some guidelines inspired in the Finnish CoBIM Requirement.

Regulations

United Kingdom

The UK regulations aim to achieve what it's known as BIM maturity levels. BIM levels were defined to measure the evolution into BIM of a certain office or professional, they reflect the level of automatization of a workflow (Figure 2) (RIBA 2014):

- Level 0: separate sources of information covering the basic assets information in paper documents.
- Level 1: separate sources of information covering the range of asset information in semi-structured electronic documents.
- Level 2: federated file-based electronic information with some automated connectivity.
- Level 3: integrated electronic information with full automated connectivity and web-stored. This is known as 'Open BIM'.

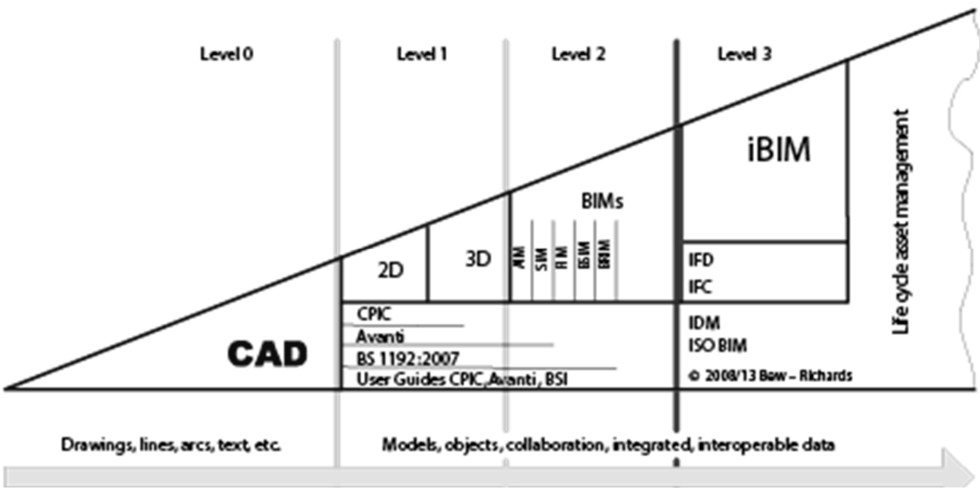


Figure 2. BIM Maturity levels. (Standards 2014)

Currently in the UK, publicly-funded constructions must meet the requirements of the standard PAS 1192-3, which aims to achieve BIM Level 2. PAS 1192 –Part 3 "Specification for information management for the operational phase of construction projects using building information modelling" (Standards 2014) is meant to be used during the O&M stage. It regulates the processes of data transfer to:

- Create an asset information model (AIM) for an existing asset or portfolio of assets.
  - Asset: item, thing or entity that has actual value to an organization (building, equipment, land, etc.)
- Exchange asset information with a project information model (PIM).
  - PIM: information model developed during the design and construction phase.
- Record information relating to the disposal, decommissioning or demolition of an asset.
- Use the AIM to support organizational requirements.
- Revise the AIM as the asset changes.
- Hold the AIM as a resource for organization.

This standard focuses on the methodology to exchange information, rather than the content this information should include. It embraces the relations between professionals, the workflow of information they manage, and it enhances the philosophy of collaboration that is needed to enable functional teams.

United States

The primary focus of the National BIM Standard – United States ® (NBIMS-US ™) is to provide standards to facilitate the efficient life-cycle management of the built environment supported by digital technology. This standard regulates the activities that are developed during the O&M stage, which are contemplated as the part of the following cycle: Design-Procure-Assemble-Operate (Figure 3):

Figure 3. Tetralogy process domains (National Institute of Building Sciences buildingSMARTalliance 2016)

It is organized in 5 chapters that focus on specifying the characterization of information and the formats of its exchange, in order to produce BIM model of diverse benefits:

1. Scope
2. Reference standards:
   2.1 OmniClass Constructive Classification System
   2.2 BIM Collaboration Format (BCF)
   2.3 LOD Specifications
3. Terms and definitions
4. Information exchange standards
   4.1 Design to Spatial Program Validation (SPV)
   4.2 Design to Building Energy Analysis (BEA)
   4.3 Design to Quantify Takeoff for Cost Estimating (QTO)
   4.4 Building Programming information exchange (BPie)
   4.5 Heating, Ventilation and Air Conditioning information exchange (HVACie)
   4.6 Water Systems information exchange (WSie)
5. Practice documents:
   5.1 BIM Project Execution Planning Guide
   5.2 BIM Project Execution Plan Content
   5.3 Mechanical, Electrical, Plumbing and Fire Protection Systems Spatial Coordination Requirements for Construction Installation Models and Deliverables
   5.4 BIM Planning Guide for Facility Owners
   5.5 Practical BIM Contract Requirements
   5.6 The uses of BIM

The chapter 5.3 is especially relevant for this research. On a sub-chapter called "File format, compatibility and completeness", it specifies a hierarchy of elements that are considered of prior interest when modelling and coordinating FM installations. These elements are called *Major Components* (National Institute of Building Sciences buildingSMARTalliance 2015):

- HVAC Duct: All ductwork, grilles, registers, diffusers, dampers, access panels, air moving equipment, maintenance clearances, and any item that may impact coordination with other disciplines.

- HVAC Piping: All overhead piping, vertical piping in shafts, connections to equipment, scheduled equipment, maintenance clearances, hangers, supports, and any item that may affect coordination with other disciplines.
- Plumbing: All overhead piping, vertical piping between floors, connections to equipment and fixtures, maintenance clearances, hangers, supports, and any item that may affect coordination with other disciplines.
- Fire protection piping: All overhead piping, branch connections, drops and heads, access panels, maintenance clearances, hangers, supports, and any item that may impact coordination with other disciplines.
- Electrical: All conduits 2” and larger, any rack of two or more conduits regardless of size, lights and fixtures, electrical pull and circuit boxes, access clearances, all cable trays, hangers, supports, raceways, and any item that may impact coordination with other disciplines.
- Framing: All king studs, headers, and any item that may affect coordination with other disciplines.

Spanish Guides

Currently in Spain there’s publicly available the uBIM guide, developed by the buildingSMART Spanish home of openBIM. This guide is an adaptation of the Finnish COBIM Requirement (2012), and aims to have an easy standard in continuous evolution to coordinate all disciplines involved on the production of BIM models. It’s composed by the following documents:

D1 General part	D2 Actual state	D3 Architectonic design
D4 Services design	D5 Structural design	D6 Quality insurance
D7 Quantifications	D8 Visualization	D9 Services analysis
D10 Energetic analysis	D11 Projects management	D12 Facility management
D13 Construction		

Document *D2 Actual state* specifies 3 levels according to the required information for modelling pre-existing buildings or their surroundings:

- Level 1: Spatial modelling (Figure 4)
- Level 2: Modelling of constructive elements
- Level 3: Modelling of constructive elements (extended) (Figure 5)

Nivel 1: Modelo Espacial	
Elemento constructivo	**Requisitos**
Espacios	
Superficie de habitaciones	Modeladas. Se añaden identificadores de espacio e información del estado actual.
Elementos del emplazamiento. Modelado del emplazamiento	
Modelo de la superficie 3D y vegetación que debe conservarse	Se definirá en cada caso
Elementos constructivos	
Suelos, entramado estructural y cubiertas exteriores	Definido en las bases del proyecto
Muros exteriores	Modelado sin detalles
ventanas	Modeladas sin divisiones
Puertas exteriores	Modeladas sin detalles
Tejados	Modelados
Elementos interiores	
Aparatos sanitarios	Definido en las bases del proyecto

Figure 4. uBIM Guide: Level 1 (BUILDING SMART Spanish Chapter 2014b)

The information related to the pre-existing installations is only considered at Level 3 (Figure 5), and its completeness is drafted by the appointment "Defined by project", therefore left to the criteria of the designers, without detailing further requirements or suggestions.

Nivel 3: Modelo de elementos constructivos (ampliado).	
Elemento constructivo	**Requisitos**
Instalaciones	La tolerancia tiene que acordarse en las bases de proyecto
Instalaciones de fontanería	Definido por proyecto
Elementos de aire acondicionado	Definido por proyecto
Instalaciones eléctricas	Definido por proyecto
Instalaciones mecánicas habituales	Definido por proyecto
Ascensores	Cotas a ejes y modelado.

Figure 5. uBIM Guide: Level 3 (BUILDING SMART Spanish Chapter 2014b)

Document *D12 Facility Management* states that a BIM model of an existing building, based on drawings and spatial measurements, is known as Inventory BIM ("BIM de inventario" in Spanish). These BIM models enabled to support FM are expected to produce .ifc format files, to allow open data transfer between software. Although COBIE is also useful in this sense, this format is not in use in Spain yet.

In this document some BIM tools that meet the IFC requirement are suggested:

- Architectonic design: AutoCAD, Revit, ArchiCAD
- Structural design: Tekla, Allplan
- Mechanical design: MagiCAD, CADS

2.3 Data sources

The process of modelling an existing building in BIM is challenging due to the lack of available or reliable information, the sources of information of existing buildings are normally paper sheets, PDFs, 2D drawings or specific databases. When the information needed to model is not available in any of them, it might be necessary to implement data capturing techniques. The following classification embraces the available methods to obtain information based on field procedures:

Table II. Data capturing techniques. (Volk et al. 2014)

Data capturing and building surveying techniques				
Non-contact techniques			Contact techniques	
Image based t.	Range-based t.	Other t.	Manual t.	Other t.
- Photogrammetry (monocular, stereo)	- Laser scanning (LADAR, LiDAR)	- Tagging (RFID, Barcodes)	- Tape measurers, calipers	
- Videogrammetry	- Laser measure.	- Pre-existing inf.	- Other	
		- Other		

The main difference between these techniques in relation with the purpose of this thesis is whether they allow or not BIM integration. The first group includes laser scanning and photogrammetry, and the second group includes tagging (RFID), tape measurers and calipers.

1st group: BIM integrative techniques

Both laser scanning as photogrammetry are based on the analysis of images, they record the surface of objects whose position can be defined in space by a naked eye. Based on the study of Volk et al (Table III), photogrammetry is cheaper, faster and lighter –regarding the data volume, it also has greater interoperability and the equipment is more durable.

Table III. Laser scanning vs Photogrammetry. (Volk et al. 2014)

Decisive features	Data capturing technique	
	Laser scanning	Photogrammetry
Applicability in existing buildings	Yes	Yes
Cost	High	Medium
Time	Medium	Fast
Spatial accuracy, Level of Detail (LOD)	High	High
Influence of size and complexity of the scene	High	High
Influence of environmental conditions	High	High
Importability into BIM	Yes	Yes
Data volumes	High	Medium
Degree of automation	Medium	Medium
Operability	Low	Medium
Equipment portability	Low	High
Equipment durability and robustness	Medium	High

As they are both commonly used, the following explanation introduces them.

Laser scanning

Commonly called Scan-to-BIM, laser scanning is the most popular process to create as-built models since 1990, the principal benefits of this technique are its accuracy, its fast implementation and its compatibility with a wide range of software and applications. However, there are still some handicaps as its high price or the vast amount of data it generates, which has later to be processed.

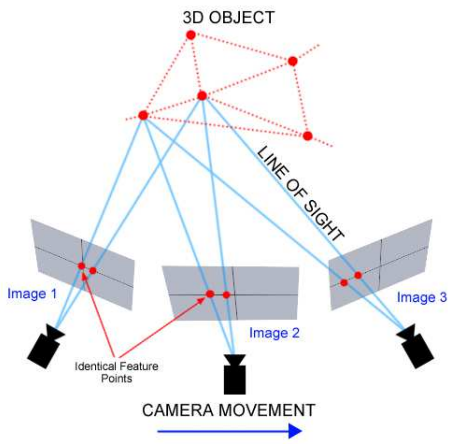
The technique is based on a device that shoots a laser at the target and registers the position of every point it finds on its way. The upper part of the gadget allows the laser to turn 270º around, contained on a vertical plane, and the lower part allows 360º rotation of such plane covering the whole space.

When the post-processing is done, those millions of registered points that were characterized by means of the (x.y.z) property, are converted to point clouds that produce the three-dimensional model. This technique is very vulnerable to the complexity of the scene, and it provides superficial information that may not be enough to model the whole pieces or materials that are needed, as the information obtained is limited to the one reachable by the naked eye.

Photogrammetry

Photogrammetry is as accurate as laser scanning while being faster and cheaper, its operability doesn't require advanced skills and the equipment is more durable while being also more manoeuvrable.

The process is based on a moving camera that takes overlapping pictures and registers specific points of reference to connect all images, then it generates 3D views that can be converted to point clouds by colour sensing and triangulation. The movement of the camera can be obtained by means of a flying drone or a ground-based system, so it's usable for both indoor and outdoor scenarios.



The use of photogrammetry has spread up in the past years due to its improved benefits in comparison with laser scanning:

- Operability: both of them have the purpose of obtaining a point cloud of the whole space, to achieve so laser scanning requires several shots at different points of the scenario, those shot-points have to be previously studied and the equipment has to be manually placed. The photogrammetry camera is easier to manipulate as the drone can be moved by remote control and the ground-based system moves independently by rails, avoiding manual placement of the equipment.
- Equipment: photogrammetry camera doesn't require specific maintenance while the laser scanning device has indeed that need, it is also a more fragile gadget than the photogrammetry camera, so its manipulation has to be performed by expert personnel.

Nevertheless, these techniques are limited to the data reachable to the naked eye, therefore are not enough for cases with high levels of spatial complexity (Anagnostopoulos et al. 2015).

2nd group: non BIM integrative techniques

Tagging (RFID)

Radio-frequency identification is a method of Automatic Identification and Data Capture (AIDC) that uses electromagnetic fields to identify and track tags attached to objects. Its use is similar to the barcode one, as there's a reader which connected to an antenna can obtain the information recorded in the tag (image), while it does not require the tag to be on the line of sigh of the reader to get the information.

Regarding its applicability to this research, its use is limited to the characterization of those objects that were produced after this technology was widely spread in the market, this phenomena occurred after 1983 when the first patent of RFID system was registered by Charles Walton in the US. Nevertheless, its use in the field of constructive materials is not very popular, so there may be components that don't have been characterized by this technology.

Tape measurers

It's the most common tool for measuring dimensions, it's composed by a strip marked longitudinally, divided in millimetres, centimetres, metres or the equivalent units in inches.

Callipers

These gadgets are used to measure the longitudinal distance between two points. Depending on their type they allow: to measure outside or inside dimensions, as well as lengths in specific directions; they also allow to draw lines at specific distances (the last type are commonly known as compasses).

2.3 Conclusions

The need to define a standardized procedure for modelling existing facilities in BIM has been pointed out as a solution that will centralize the whole FM information. It will improve the work-flows of information between managers. Therefore it will optimize time and resources that are currently wasted in non-automatized and unconnected procedures. It will also provide a reliable database as a decision-making tool for future refurbishments, integrated maintenance plans and specific analysis related to the energetic behaviour of the building.

The future benefit of this guide will be focused on educational buildings, which compose 43% of current stock of public buildings in the Catalonian Region.

Regarding the regulations applicable to BIM modelling for FM:

- In the UK, the specification PAS 1192 –Part 3 requires that from 2016 on, publicly funded projects must be developed up to BIM level 2 of maturity, i.e. automated connectivity among the software in which the project relies on. Regarding the development of AIM for existing assets, it "*provides a mechanism for existing assets to enter the PAS 1192-3 management process without relying on a project information model (PIM)*". It also specifies how the workflows should organize among specialists and files.
- US: NBIMS-US V3 Specification: Its structure relies on the OmniClass Constructive Classification System. It specifies a useful hierarchy of FM elements, called *Mayor Components*, which shall be modelled as a minimum requirement for FM purposes.
- Spanish uBIM guide recommends to use .ifc file format to allow open data transfer between BIM software, as COBIE is not yet available in Spain. Regarding the modelling of existing installations in BIM, the data requirements for such purpose are not defined.

In relation to data capturing techniques, the review concludes that although they suppose a huge advantage on the characterization of the facility environments and elements, none of them provide by itself all the needed information to generate a BIM model. BIM integrated techniques shall be complemented with data from other types of manual tests. The output of these techniques always require further modelling and data processing, as the output is a point cloud insufficient to deliver the complete BIM model as an automatized procedure. The lack of access to BIM integrated techniques is also a handicap, as they are expensive and not commonly available for facility managers. Based on this facts, it becomes clear that BIM integrative techniques are not reliable for the automatic generation of BIM models, so this research will confront its development as a process done independently from them.

3. METHODOLOGY

The methodology to develop the Guide for modelling existing building in BIM will embrace the following steps:

1. *Define the most appropriate classification system,* in order to organize the elements of the building inside the model.
2. *Define the required information* of these elements, by means of the Level of Development and Level of Information needed for every category of elements of the building.
3. *Define the procedure to centralize this information,* regarding both the search of information and the informatization of it.

This guide will be implemented in a case study: GAIA building at UPC campus Terrasa.

4. GUIDE FOR MODELLING

This guide is an improvement of the research "Study of the modelling process in BIM of an existing building in Campus Terrasa" (Seuma Areñas 2016), this improvement embraces the following aspects:

- Classification System.
  In order to organize the elements of the building, previous work relied on OmniClass Construction Classification System. The practical implementation of this classification has important disadvantages, so this guide proposes to rely on UniFormat II Classification System, as an easier and more useful way to organize the elements of the building.

- Specify data requirements based on its relevance for FM purposes: LOD/LOI.
  In order to define the properties that should be modelled of each category of elements, previous work relied on the Level of Development Guide. LOD concept focus on graphical information, and lacks the definition of non-graphical properties. To specify the requirements regarding non-graphical properties, this guide relies on the Level of Information required by facility managers, so the final requirements of information to model is defined by both LOD and LOI, for each category of elements of the building.

- Centralize information without intermediate software.
  Previous work proposed: 1st to search the building's information in the available sources, 2nd to storage it in an intermediate software as excel, and 3rd to introduce it in the BIM model. This guide provides a Revit template configured to classify information without intermediate software, joining previous steps 2 and 3. This Revit template specifies the data to characterize in each category, based on its adequate LOD and LOI.

- Evaluate the Level of Realism of the model.
  This test will evaluate how realistic the model is based on 2 indicators:
  1. Parameter's Quality: the source of information that provided each data will define how reliable this data is, data taken on the site will have the highest Parameter´s Quality, as it is absolutely reliable, and data based on Basic Project will have the lowest Parameter's Quality, as it is not so reliable.
  2. Parameter's Relevance: this indicator will adjust the influence that each data has, based on its influence in the facility management.

  The ponderation of this two values will define the LOR of each type of element of the building, the LOR of each group of elements, and the LOR of the overall model.

4.1 Classification Systems

4.1.1 General information

In order to organize the concepts related to the AEC industry, several institutions have provided different classification systems. This classifications aim to embrace every concept related to the built environment, since the conceptual design of the infrastructure, to its later maintenance and demolition, involving every agent, procedure and object of the process. From this wide scope, this research will focus on the elements that get involved during the O&M stage of a building, specifically related to its FM. For this field, the information to organize was generally appointed by Lin. et al. as follows:

Table IV. The detailed required sheet of BIM model for FM. (Lin et al. 2016)

Profile	Basic info.	[...]
Model parameters	Geometric info.	[...]
	Equipment detail info	[...]
External Links Info.	Supplementary Info.	[...]
	Maintenance records	[...]

The information is organized in three groups: Profile, Model parameters and External links information:

- Profile: it generally characterizes the element, it's system and equipment type.
- Model parameters: this is the most important part, depending on the LOD/LOI achieved in the equipment specifications and functions, the model will be useful for FM tasks.
- External links information: this part embraces information that might not be introduced on the model, even that it is important for the management of the building (warranty, maintenance manual, record book of maintenance staff, etc.)

The part of Model parameters, embraces all the equipment specifications that each element has, and the information that this part requires will be defined by means of the Level of Development and the Level of Information

4.1.2 Classification systems

In order to organize this information, the systems currently available are: OmniClass Constructive Classification System (OCCS), Master Format, UniFormat II and Uniclass (Table V).

Table V evaluates which of them could be applicable to this research:

Table V. Comparison between classification systems

	OCCS	MasterFormat	UniFormat	Uniclass
Grouping principle (Afsari & Eastman 2016)	faceted	hierarchical	hierarchical	faceted
Field of focus	Entire build environment	Constructive stage	Entire built environment	Entire built environment
BIM integrative	Partial	Complete	Complete	None

MasterFormat and Uniclass have been discarded, as MasterFormat focuses on the constructive stage of the project, and does not classify facility management elements; and Uniclass's coding system has yet to be integrated in BIM software.

OCCS and UniFormat are two possible options, as their scope embraces facility management elements. The main difference of their approach is their grouping principle, OCCS is faceted, which means that one unique entity can be classified from multiple points of view, so a physical element can have different codes depending on the feature of study. UniFormat is organized hierarchically, which means that objects are characterized by their physical properties, rather than a feature they present in a certain stage of the constructive process. So far they are both suitable options, but a more precise analysis of advantages and disadvantages (Table VI) will determine that UniFormat is the best choice.

Table VI. Advantages and disadvantages of OCCS and Uniformat

	Advantages	Disadvantages
OCCS	. OCCS code: characterized in the core of the Revit family, rather than in the item that is modelled in the whole model of the building. . Wider scope of service elements, and a more precise definition of them.	. Don't classify some structural elements. . Categories of OCCS not directly characterizable in BIM software. . LOD classification is not directly applicable to OCCS categories.
UniFormat	. Categories of UniFormat directly characterizable in BIM software.	. Assembly Code of an element: characterized from the model of the building, rather than in the core of the element.

Although OCCS presents important advantages, the current incapability of BIM software to characterize according to some OCCS categories, disables it as suitable classification system. If further improvement of BIM software solved this handicap there would be still an important handicap for the purpose of this guide, which is the lack of correspondence between OCCS and LOD categories.

The chosen classification system is therefore UniFormat II, as BIM software allow the direct characterization of the elements of the building according to UniFormat categories. Nevertheless, UniFormat II presents an important disadvantage, which is the fact that the Assembly code is characterized in the model of the building, rather than in the core of the equipment's model. In cases in which the model of the building is organized in several minor files, the consistency between files is not guaranteed, and it has to be manually verified that the code attached to a certain object is the same in every minor file in which that equipment has been introduced. For example: imagine that the building to model is composed by several identical classrooms, and the model is assembled in a way in which the classroom is modelled once, as a minor model, and repeated several times in the mayor model. Imagine that this type-classroom has a lamp, with a certain Assembly Code, this code cannot be characterized at the core of the lamp model, nor at the core of the classroom model, it has to be characterized at the mayor model, as many times as the lamp is repeated. This requires higher modelling time and implies a bigger error range. The solution for this issue is to personally verify that the Assembly Code is equal for a certain item, in the previous example: to personally verify that every lamp has the same Assembly Code in the general model.

4.1.2.1 UNIFORMAT II

UniFormat classification relies on the following categories to organize the elements of a built facility:

A) SUBSTRUCTURE
B) SHELL
C) INTERIORS
D) SERVICES
E) EQUIPMENT & FURNISHINGS
F) SPECIAL CONSTRUCTION & DEMOLITION

Each category is composed by several subcategories, which organize physical entities of the building. For the purpose of this research, the subcategories that integer the Services (Table VII) will be considered as main categories, due to their relevance for FM purposes.

Table VII. Extract of "ASTM Uniformat II Classification for Building Elements (E1557-97)" (Charette & Marshall 1999)

CATEGORY	SUBCATEGORY	
D) SERVICES	D10 Conveying	D1010 Elevators & Lifts
		D1020 Escalators & Moving Walks
		D1090 Other Conveying Systems
	D20 Plumbing	D2010 Plumbing Fixtures
		D2020 Domestic Water Distribution
		D2030 Sanitary Waste
		D2040 Rain Water Drainage
		D2090 Other Plumbing Systems
	D30 HVAC	D3010 Energy Supply
		D3020 Heat Generating Systems
		D3030 Cooling Generating Systems
		D3040 Distribution Systems
		D3050 Terminal & Package Units
		D3060 Controls & Instrumentation
		D3070 Systems Testing & Balancing
		D3090 Other HVAC Systems & Equipment
	D40 Fire Protection	D4010 Sprinklers
		D4020 Standpipes
		D4030 Fire Protection Specialties
		D4090 Other Fire Protection Systems
	D50 Electrical	D5010 Electrical Service & Distribution
		D5020 Lighting and Branch Wiring
		D5030 Communications & Security
		D5090 Other Electrical Systems

4.2 Level of Development and Level of Information

In order to define the information that should be modelled, it was necessary to rely on this to concepts, as they focus, respectively, on the graphical and non-graphical properties of the elements.

The focus of stablishing the requirements based in LOD and LOI, diverges from the general one of the research made up-to-date, current literature rely only in LOD specification, to define information to model existing facilities for FM purposes, and require up to LOD 500 to define the properties of the services (Designer 2013). But achieving such LOD requires high modelling time, file size and low speed of work. By splitting the requirements and limiting those of the services for their non-graphical information (LOI), we focus on their key features and afford modelling time and file size, and increase speed of work.

4.2.1 LOD

There are six levels of development according with the AIA (Figure 6):

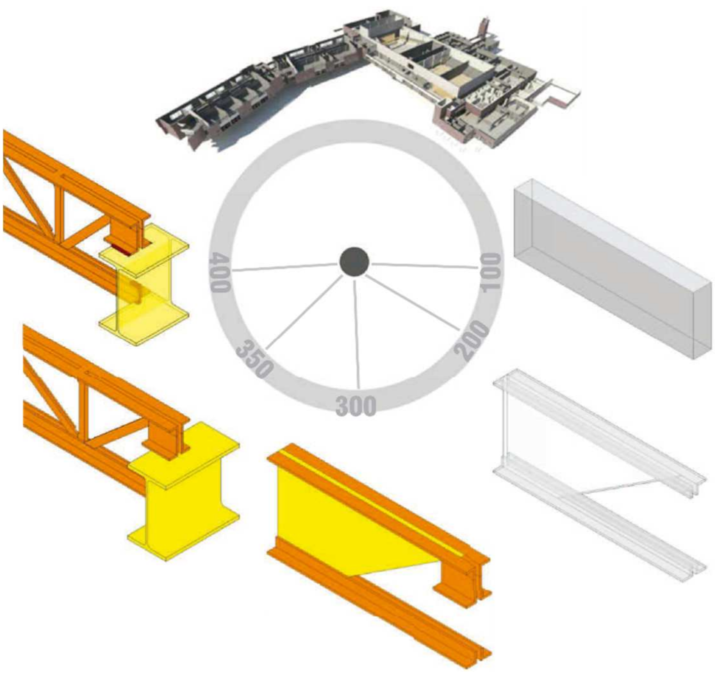


Figure 6. Levels of Development According to the American Institute of Architecture. (Forum 2015)

- LOD 100: The Model Element may be graphically represented in the Model with a symbol or other generic representation.

- LOD 200: The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

- LOD 300: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

- LOD 350: The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.

- LOD 400: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.

- LOD 500: The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

The concept of Level of Development is interrelated with the concepts of Level of Reliability and Level of Completeness (see section 2.1). Treldal et al. explained this relation as follows:

Table VIII. BIMForum 2015 LOD definition for D2010.20-domestic water equipment supplemented with an interpretation of corresponding detailing, Level of Reliability (LOR) and Level of Completeness (LOC). (Treldal et al. 2016)

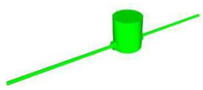
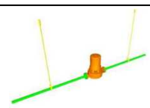
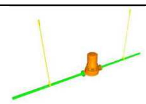
LOD 100	LOD 200	LOD 300	LOD 350	LOD 400
-				
Diagrammatic or schematic model elements, conceptual and/or schematic layout/flow diagram; design performance parameters as defined in BIMXP to be associated with model elements as non-graphic information.	Schematic layout with approximate size, shape, and location of equipment; approximate access/code clearance requirements modelled; design performance parameters as defined in BIMXP to be associated with model elements as non-graphic information.	Modeled as design-specified size, shape, spacing and location of equipment; approximate allowances for spacing and clearances required for all specified anchors, supports, vibration and seismic control that are utilized in the layout of equipment; actual access/code clearance requirements modelled.	Modeled as actual construction elements size, shape, spacing and location/connections of equipment; actual size, shape, spacing and clearances required for all specified anchors, supports, vibration and seismic control that are utilized in the layout of equipment.	Supplementary components added to the model required for fabrication and field installation.
Interpretation: Detailing = diagrammatic LOR = conceptual LOC = diagrammatic	Interpretation: Detailing = medium LOR = approximate LOC = generic level	Interpretation: Detailing = fine LOR = design-specified LOC = type level	Interpretation: Detailing = fine LOR = actual LOC = component level, design	Interpretation: Detailing = fine LOR = actual LOC = component level, fabrication

Table VIII reflects the fact that LOD increases progressively the detailing of the element (the accuracy of its geometry), and the reliability of its non-graphical properties; this criteria is operative during the design stage of the building, as it accompanies the process of design as the elements get more defined until they are built; for the purpose of this research, this standard is only useful in the cases in which geometry is a key feature.

4.2.2 LOI

Currently there is no standard that stablishes the properties to define each element, according to a certain set of levels that increase their requirements. Based on the recommendations of facility managers, this non-graphical information should include, in a general basis:

- Brand and model of equipment
- Source of information of data
- Relevant technical properties

Based on this requirements is defined the information of each category of elements. The highest LOI will be required in the Services categories, focusing on the modelling of Mayor equipment, because it takes part in the facility manager tasks of maintenance, while minor elements won't be considered (like pipes, air ducts or electric nets) as they don't get involved in the facility manager tasks of maintenance.

4.2.3 LOD/LOI requirements for Uniformat II categories

UniFormat II is organized in several categories and sub-categories (chapter 4.2.2.1), which correspond to the categories found in the LOD guide.

This classification will be the guide to organize the objects inside the BIM model. For each of these categories, the informational requirements will be stablished by LOD or LOI (Table IX), as follows:

Table IX. LOD/LOI for Uniformat II

ELEMENTS		Level of Detail	Level of Information
Level 1	Level 2		
Substructure	Foundations Subgrade enclosures Slabs-On-Grade Superstructure	LOD 200	Low
Shell	Exterior vertical enclosures	LOD 400	Medium
	Exterior horizontal enclosures	LOD 300	
Interiors	Interior construction	LOD 200	Low
	Interior finishes	LOD 200	
Services	Conveying	LOD 200	High
	Plumbing	LOD 200	
	HVAC	LOD 200	
	Electrical	LOD 200	
Equipment and furnishings	Furnishing	LOD 200	Low

These informational requirements have been set based on the needs of the facility manager of a typical educational building, as current maintenance of educational buildings requires special attention to the following elements:

- Shell:
  Aluminium façades and metallic components of the building's skin: they require periodic verification (each 6 months) of opening mechanism and metallic profiles.
  Windows require periodic verification (each 6 months) of the sealing gaskets.

- Conveying: elevators and lifts require periodic service of:
  Cleaning of the lighting and machinery room (each month).
  Verification of the integrity of access doors and mechanical equipment (each 6 months).

- Plumbing:
  Water deposits and chillers require periodic verification (each 6 months) of their correct performance.
  The water pressure group require periodic verification (each 6 months) of the heating power.
  Heat pumps require periodic verification (each 6 months) of their heating and cooling power.

- HVAC:
  Air diffusors require periodic verification (each year) of their heating and cooling power.
  Centralized units of acclimatization require periodic verification (each month) of their heating and cooling power, air filters and water filters.

- Electrical:
  The electric panel boards require periodic verification (each 2 years) of the integrity of the equipment.
  The distributing panel boards require periodic verification (each year) of the the integrity of the equipment.

This guidelines have been obtained from the Maintenance plan of the case of study of this research: Gaia building.

Based on this needs, the final LOI and LOD required for each element is detailed in tables (****), each table is organized as follows:

Element to be detailed
Data required for each LOI
LOD

Table X. LOI/LOD Structural foundation

01.01 Structural Foundation			
Level	Structural Material	Width	Length
LOD 200:. Approximate size and shape of foundation element			

Table XI. LOI/LOD Floor

01.02 Floor			
Area	Level	Structural Material	Depth
LOD 200: . Floor with approximate dimensions . Approximate supporting framing members . Structural grids defined			

Table XII. LOI/LOD Structural column

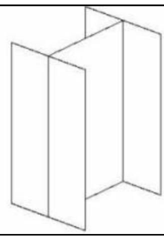
01.03 Structural Column					
Base Level	Top Level	Structural Material: Class	Length	Section Shape: Height	Section Shape: Width
LOD 200: . Floor with approximate dimensions . Approximate supporting framing members . Structural grids defined					

Table XIII. LOI/LOD Stairs

01.04 Stair				
Base Level	Top Level	Material	Actual Riser Height	Actual Number of Risers

LOD 200:
. Generic model element with simplified treads and risers.
. Nominal overall unit scope shall include:
  . Nominal plan dimensions (length, width)
  . Nominal vertical dimensions (levels, landings)

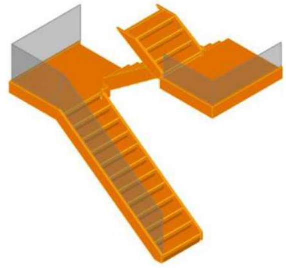


Table XIV. LOI/LOD Exterior vertical enclosures: Façade

02.01 Façade				
Area	Orientation	Type	Structural Material	Heat Transfer Coefficient (U)

LOD 400:

Cold formed metal framing is developed with sufficient elements that support the fabrication of the CFMF system.

Image notes:
1) Connection content is development in the wall elements. This includes but is not limited to fasteners, clips, and other related hardware.

2) Cladding and sheathing are not shown for clarity in this image.

Table XV. LOI/LOD Exterior vertical enclosures: Window

02.02 Window					
Orientation	Width	Head Height	Heat transfer coefficient (U)	Brand	Model

LOD 400:
Frame profiles
Glazing sub-components (gaskets)
Attachment components

Table XVI. LOI/LOD Interiors: Wall

03.01 Wall	
Base Constraint	Width
LOD 200 Generic wall objects separated by type of material (e.g. gypsum board vs. masonry). Approximate overall wall thickness represented by a single assembly. Layouts, locations, heights, and elevation profiles are still flexible.	

Table XVII. LOI/LOD Interiors: Doors

03.02 Door				
Level	Frame Material	Width	Head Height	Fire Rating
LOD 200 Generic wall objects separated by type of material (e.g. gypsum board vs. masonry). Approximate overall wall thickness represented by a single assembly. Layouts, locations, heights, and elevation profiles are still flexible.				

Table XVIII. LOI/LOD Elevators and lifts

04.01 Elevators and lifts					
Level	Brand	Model	Capacity (nº people)	Speed (m/s)	Dimensions (m)
LOD 200: Generic representation of the system envelope, including critical path of travel zones.					

Table XIX. LOI/LOD Water tanks

05.01 Water tanks						
Level	Brand	Model	Volume (l)	Accumulation temperature	Distribution temperature	Dimensions (m)

LOD 200
Schematic layout with approximate size, shape, and location of tank(s);
Approximate access/code clearance requirements modelled;
Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.

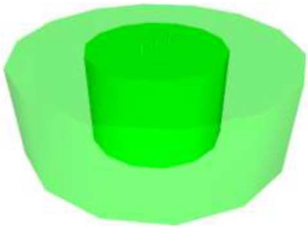


Table XX. LOI/LOD Water pressure group

05.02 Water pressure group		
Level	Power (CV)	Flow (l/s)

LOD 200
Schematic layout with approximate size, shape, and location of tank(s);
Approximate access/code clearance requirements modelled;
Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.

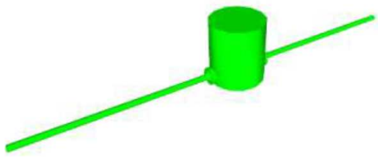


Table XXI. LOI/LOD Water pumps

05.03 Water pumps				
Level	Brand	Model	Pressure (bar)	Water flow (m3/h)

LOD 200
Schematic layout with approximate size, shape, and location of tank(s);
Approximate access/code clearance requirements modelled;
Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.

Table XXII. LOI/LOD Boiler

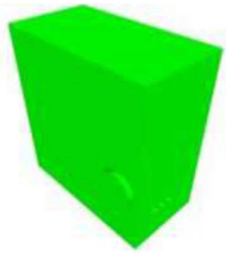
06.01 Cooling generating systems, boiler					
Level	Brand	Model	Type of supply (gas, electrical, biomass)	Heating power (kWc)	Power supply
LOD 200 Schematic layout with approximate size, shape, and location of element(s); Approximate access/code clearance requirements modeled; shaft requirements modeled; Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.					

Table XXIII. LOI/LOD Heat pumps

06.02 Cooling generating systems, heat pumps					
Level	Brand	Model	Heating power (kWc)	Cooling power (kWc)	Power supply
LOD 200 Schematic layout with approximate size, shape, and location of element(s); Approximate access/code clearance requirements modeled; shaft requirements modeled; Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.					

Table XXIV. LOI/LOD Chiller

06.03 Cooling generating systems, chiller				
Level	Brand	Model	Electric power (kWe)	Cooling power (kWc)
LOD 200 Schematic layout with approximate size, shape, and location of element(s); Approximate access/code clearance requirements modeled; shaft requirements modeled; Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.				

Table XXV. LOI/LOD Air handling units

06.04 Terminal and package units, air handling units							
Level	Brand	Model	Air renovation	Type of energy recovery system	Heating power (kWc)	Cooling power (kWc)	Electric power (kWe)

LOD 200
Schematic layout with approximate size, shape, and location of element(s);
Approximate access/code clearance requirements modeled; shaft requirements modeled;
Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.

Table XXVI. LOI/LOD Fan-coils

06.05 Terminal and package units, fan-coils					
Level	Brand	Model	Heating power (kWc)	Cooling power (kWc)	Electric power (kWe)

LOD 200
Schematic layout with approximate size, shape, and location of element(s);
Approximate access/code clearance requirements modeled; shaft requirements modeled;
Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.

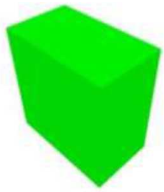


Table XXVII. LOI/LOD Splits

06.06 Terminal and Package units, splits (interior unit)							
Type	Level	Brand	Model	Heating power (kWc)	Cooling power (kWc)	Electric power (kWe)	Dimensions (m)

LOD 200
Schematic layout with approximate size, shape, and location of element(s);
Approximate access/code clearance requirements modeled; shaft requirements modeled;
Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.

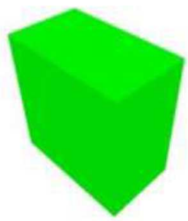


Table XXVIII. LOI/LOD Electric panelboard

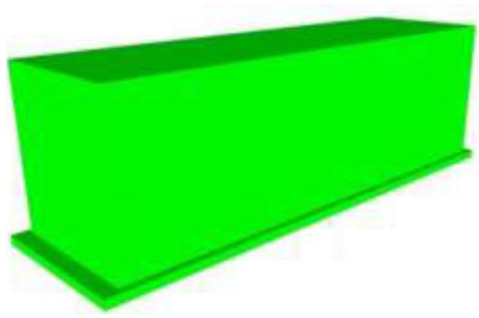
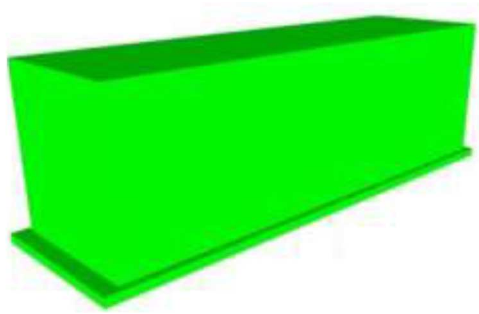
07.01 Electrical Service/Distribution, electric panelboard	
Level	Electric power (kWe)
LOD 200 Schematic layout w ith approximate size, shape, and location of element(s); Approximate access/code clearance requirements modeled; shaft requirements modeled; Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.	

Table XXIX. LOI/LOD Distributing panelboard

07.02 Electrical Service/Distribution, distributing panelboard		
Level	Dimensions (m)	Electric power (kWe)
LOD 200 Schematic layout w ith approximate size, shape, and location of element(s); Approximate access/code clearance requirements modeled; shaft requirements modeled; Design performance parameters as defined in the BIMXP to be associated with model elements as non-graphic information.		

4.3 Centralize information

The third improvement achieved in this guide focuses on centralizing information. Previous work proposed to search the required information, store it in an intermediate software as excel, and latterly introduce it in the BIM model. This research has developed a Revit template configured to classify information without intermediate software, substituting previous excel files by Revit schedules, which are automatically completed inside the file as the model evolves. This chapter explains basic concepts of Revit, and the configuration process of Revit schedules.

4.3.1 Basic concepts of Revit

Revit currently organizes its entities based on a clear hierarchy (figure 7), in this system, the top level is generic, and the bottom level is very specific. Every property defined in a certain level will characterize all the elements below it on the hierarchy. These concepts are defined and exemplified in table XXX.

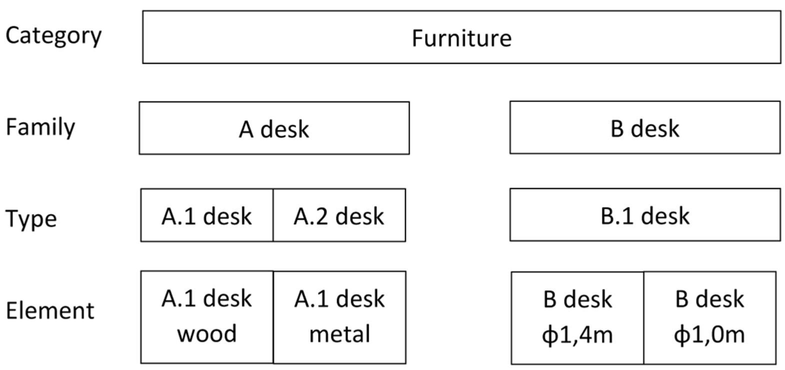


Figure 7. Revit structure of hierarchy. (Coloma 2010)

Table XXX. Revit general concepts (López Oliver 2015)

Concept	Definition	Example
Cathegory (C.)	Group that embraces objects based on their function.	Doors, axis
Annotation C.	Cathegory that embraces objects that does not exist in the building but are useful for their definition.	Axis
Model C.	Cathegory that embraces material objects of the model.	Doors
Family	Group of objects from the same cathegory that contain parametric rules to generate analogous models.	Simple door
Type	Sub-group of elements of the same family that share parameters.	Simple door 80cm
Element	Each one of the specific elements that can integer a BIM model.	Each one of the doors of the model
Parameter	Variable that allow to control properties or dimensions of objects.	Height

In terms of files, each family constitutes one file (simple_door.rvt), inside this file, it's possible to configure different types based on parameters. In the model of a building, we can model a door based on that family, and it becomes an element.

4.3.2 Configuration of Revit Schedules

This research has developed a Revit template file (Annex B), configured to automatically classify the information inside the model, by means of several schedules which hold the properties of the elements of each Workset. A Revit Schedule is a table that lists the elements of a certain type, and their properties. Inside the Annex B, schedules organize the elements according to UniFormat II categories (chapter 4.2.2.1). Each of this categories constitute a Workset inside the model. A Workset is a collection of elements, several Worksets organize the elements of the building according to the grouping criteria of the modeller, in this case the grouping criteria is defined by the categories of UniFormat II, therefore the Worksets found inside this file are:

- Substructure
- Shell
- Interiors
- Conveying
- Plumbing
- HVAC
- Electrical

Each schedule stablishes the properties to model, for each type of element of every Workset. This properties correspond to the desired Level of Development and Level of Information of each category of UniFormat II, defined in chapter 4.3.2.

In Revit, these properties are called parameters, they define a certain data of a family. For the relevance of this research there are 2 types of parameters: parameters by origin and shared parameters. In terms of software, they lie respectively:

a) Parameters by Origin: this parameters appear in every Revit model by default, for example, the height of a pillar.
b) Shared parameters: these parameters are created manually, and lie in a file called *Shared parameters.txt,* for example the Heating Power of the boiler.

Parameters by origin are defined by default in each family, and considered by default when generating schedules of that family. Computationally, they lie inside each family. Shared parameters lie in an external file. If we want to create a parameter in a family (for example, the Heating Power of the boiler), and then evaluate it in the general model of the building, shared parameters are the only ones that can be considered in both files. One Revit model can only rely in one Shared parameters file.

Process to create *Shared parameters.txt*, and to configure Revit Schedules

1. Inside the family to consider, open the Shared Parameters dialog, create a new Shared parameters file, and add a new shared parameter:

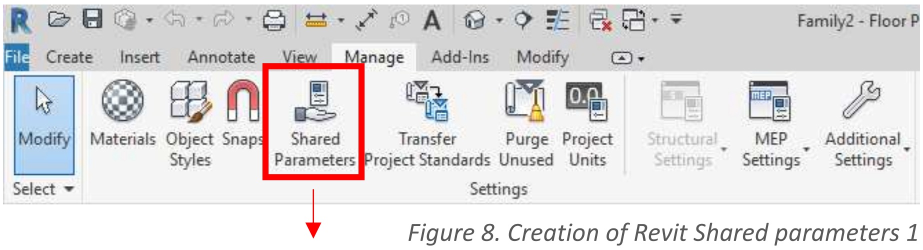
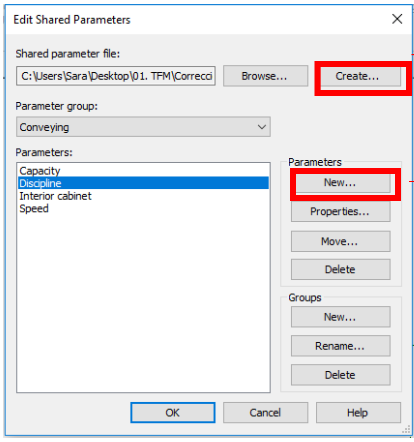


Figure 8. Creation of Revit Shared parameters 1



Save in the PC as *Shared parameters.txt*

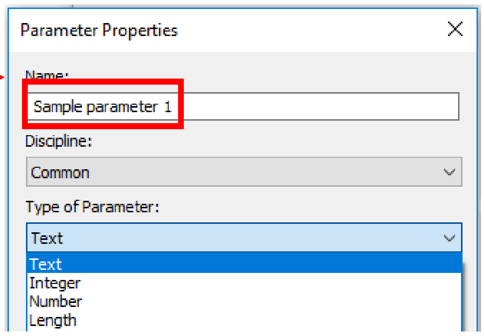


Figure 10. Creation of Revit Shared parameters 2

Figure 9. Creation of Revit Shared parameters 3

2. Once we have the parameter, it is inside the Shared parameters file. We open the Family Types panel:

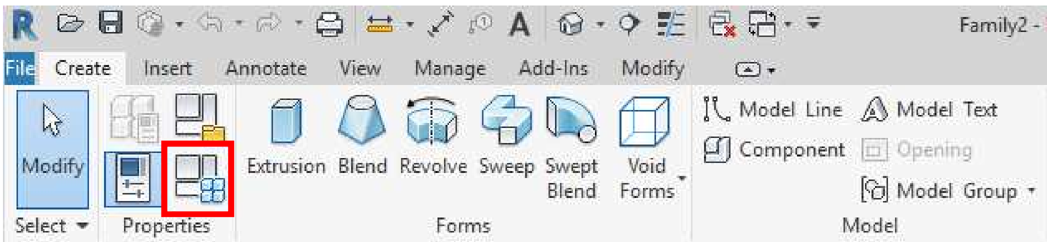


Figure 11. Revit Family Types panel

3. Inside the Family Types panel, we will find origin parameters created by default. We create a new parameter of Parameter Type: Shared parameter:

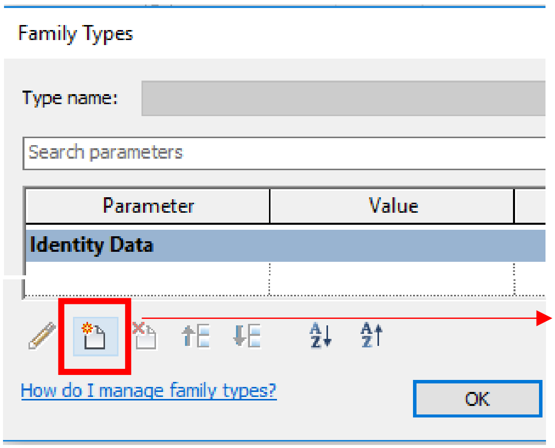


Figure 13. Revit Family Types panel: creation of new parameter

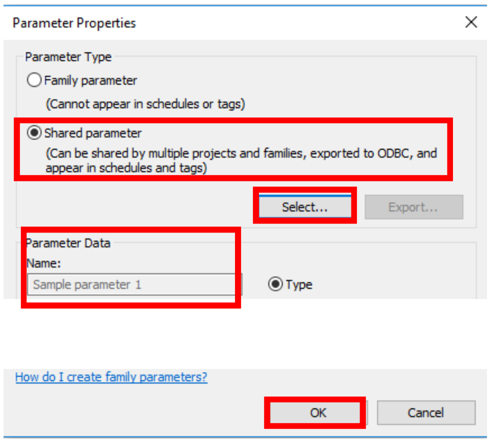


Figure 12. Revit Family Types panel: new parameter configuration

4. Now it should appear in the Family Types:

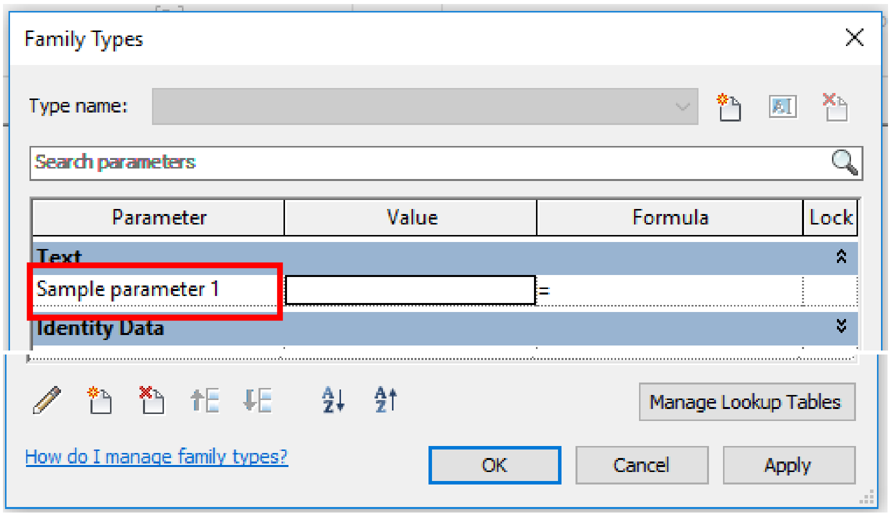


Figure 14. Revit Family Types panel: with new parameter

5. Once we have created this new parameter, we save the Family and we load it in the model of the building.

6. Once in the model of the building, we go to the schedule that corresponds to its Workset, and add a new parameter:

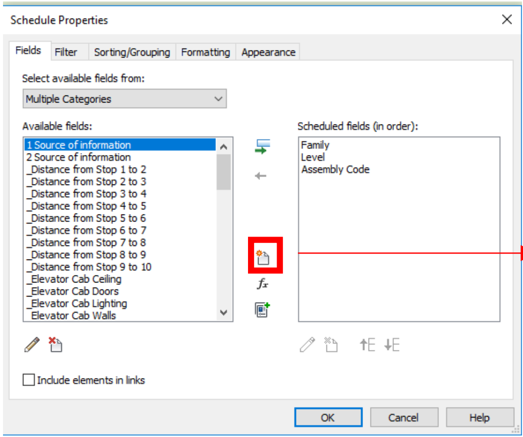


Figure 15. Revit Schedule Fields panel

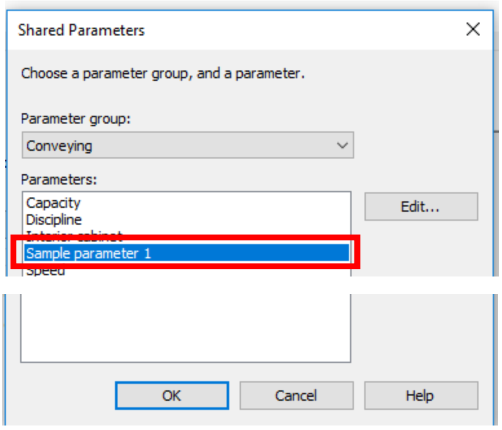


Figure 16. Revit Schedule Fields panel: new parameter

7. Now we can add it to the schedule:

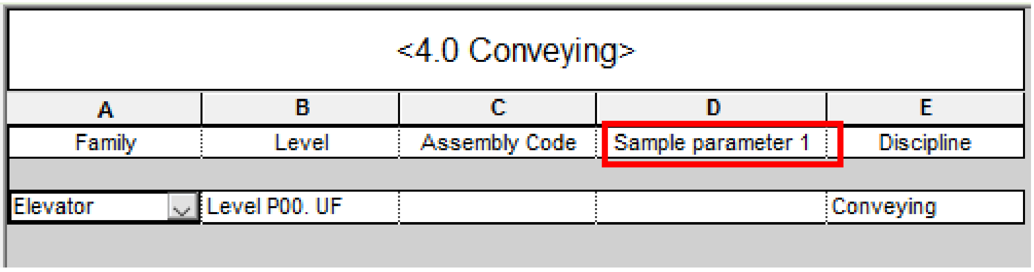


Figure 17. Revit Schedule with new parameter

Based on this process, every property of every Workset was introduced in the *Shared parameters.txt* file, ordered according to the categories of UniFormat II, and then added to the Revit Schedules of the template. If the user of this guide downloads a generic family for an equipment of his building, and wants to characterize it with the adequate shared parameters, he will easily find the parameters that corresponds to its category in the *Shared parameters.txt* file. Once this family is properly characterized, it will appear in its corresponding schedule, allowing the definition of its properties.

4.4 Level of Realism test

The general focus of this test is based on this concept:

Equation 1. Level of Realism

Level of Realism (LOR) = Parameter's Quality (PQ) x Relevance (R)

The LOR of every element considers the Parameter's Quality (PQ) and its Relevance (R). PQ reflects the reliability of data, based on the source of information it was obtained from. R reflects the influence that such data has for facility management purposes. The process of calculation is illustrated in figure 18.

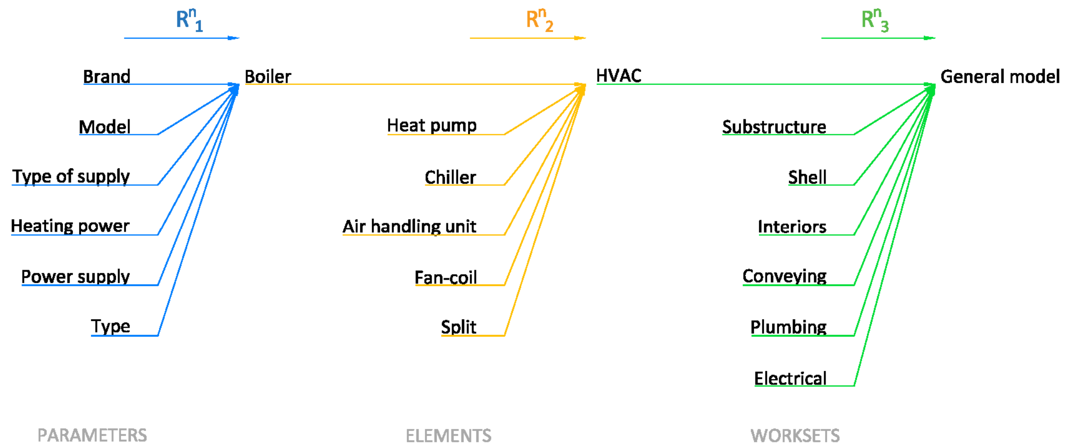


Figure 18. LOR calculation process.

At the beginning of the process, each parameter is substituted by its Parameter's Quality. PQ is defined based on the reliability of the source of information that provided each data:

- 1 in-place verified data
- 0,9 data based on As built document
- 0,75 data based on Executive project and Maintenance plan
- 0,5 data based on Basic project

As explained in figure 18, we obtain:

LORelement = Average (PQ parameter x R_1 parameter) *Equation 2. LOR element*

LORworkset = LOR element x R_2 element *Equation 3. LOR workset*

LOR model =LOR workset x R_3 workset *Equation 4. LOR model*

The relevance (R) is a percentile value, it aims to adjust the incidence of each parameter, element or workset, inside the group it belongs to. This means, that inside the LOR of an element, the parameters that have the highest incidence are the ones that get involved in frequent facility management tasks. Inside the LOR of a workset, the elements that have the highest incidence are the ones considered as priority for facility management tasks. Inside the LOR of the model, the worksets that have the highest incidence are the ones that get involved in frequent facility management tasks.

4.1.1 R_1 Parameters Relevance

To compute the LOR of each element, R_1 will adjust the influence of each parameter. R_1 has been stablished based on the needs of the facility manager: parameters that are necessary for periodic services of maintenance (chapter 4.2.3), have been considered as of 1st relevance: $R^1{}_1$. Parameters that don't interfere directly in FM periodic services, but could be important in case of refurbishment, have been considered as of 2nd relevance: $R^2{}_1$. Characteristic parameters, which rarely will be involved in facility maintenance tasks, have been considered as of 3rd relevance: $R^3{}_1$. Table XXXI explains the final R_1 assigned to each parameter:

Table XXXI. R1 Parameters Relevance

Element	$R^1{}_1 = 0,1$	$R^2{}_1 = 0,8$	$R^3{}_1 = 0,5$
Struc. foundation	Level	Structural material	Width, length
Floor	Level	Structural material, depth, function	
Structural column	Level	Structural material, length, height, width	
Stair	Base level, top level	Material	Riser height, number of risers
Façade	Orientation, width, height, heat transfer coefficient, structural material		
Window	Orientation, width, height, heat transfer coefficient	Brand, model	
Wall	Level	Width,	
Door	Level, fire rating	Frame material, width, head height	
Elevators and lift	Level, brand, model, capacity, speed, dimensions		
Water tanks	Level, brand, model, volume, accumulation temperature, distribution temperature, dimension		
Water press. group	Power, flow		
Water pumps	Level, brand, model, pressure, water flow		
Boiler	Level, brand, model, type of supply, heating power, power supply, type		
Heat pump	Level, brand, model, heating power, cooling power, power supply, type		
Chiller	Level, brand, model, electric power, cooling power		
Air handling unit	Level, brand, model, air renovation, type of energy recovery system, heating power, cooling power, electric power		
Fan-coil	Level, brand, model, heating power, cooling power, electric power		
Split	Level, brand, model, heating power, cooling power, electric power, dimensions, type of refrigerant		
Electric panelboard	Level, electric power		
Distrib. panelboard	Level, dimensions, electric power		

4.1.2 R_2 Elements Relevance

To compute the LOR of each Workset, R_2 will adjust the influence of each element:

- Worksets Substructure and Interiors, all elements are considered as of equal importance: foundation, floor, column, stair, wall and door.

- Workset Shell, this proportion will be stablished in respect to the area of the elements (m^2 of window, m^2 of opaque façade)

- Worksets Conveying, Plumbing, HVAC and Electrical. The influence of each element will be stablished according to a hierarchy of elements in each installation, defined by the facility manager of a typical educational building.

The final R^n_2 of each elements is indicated in table XXXVII:

Table XXXII. R^n_2 Elements Relevance

Workset	Element	R^n_2
Substructure	Foundation, floor, column, stair	25% each
Shell	Window, opaque façade	m2 of element / m2 total elements (%)
Interiors	Wall, door	50% each
Conveying	Elevator, lift	100%
Plumbing	Water tank	60%
	Water pressure group	40%
HVAC	Boiler	30%
	Heat pumps	10%
	Chillers	20%
	Air handling units	20%
	Fan-coils	10%
	Splits	10%
Electrical	Electric panelboards	60%
	Distributing panelboards	40%

4.1.3 R_3 Worksets Relevance

To compute the LOR of the model, R_3 will adjust the influence of each Workset.

According to the Maintenance Plan of a typical educational building, the Service that requires more frequent monitoring is the HVAC installation, which require monthly maintenance of centralized units of acclimatization. Shell, Conveying, Plumbing and Electrical require yearly maintenance, and Substructure and Interiors require revision every more than 1 year. Based on this 3 levels, the relevance of each Workset is the indicated in table XXXIII:

Table XXXIII. R3 Worksets Relevance

R^1_3 = 20%	R^2_3 = 15% each	R^3_3 = 10% each
HVAC	Shell, Conveying, Plumbing, Electrical	Substructure, Interiors

The final LOR of the model will be computed as the summation of each LOR of Workset, pondered according to the Relevance of each of them.

A practical example of the development of this method is found in the case of study (chapter 5.3).

4.5 Guide for modelling existing buildings in BIM (Annex A)

The outcome of this research is a guide (Annex A) which addresses the process of modelling existing buildings in BIM, for facility management purposes. The process for modelling is organized in 4 chapters:

- 1 File setting
- 2 General modelling
- 3 Services modelling
- 4 LOR test

The objective of chapters 1-3 is to find certain information about the building to model. In these chapters, the guide:

- Defines which information should be found.
- Defines a Procedure of Information Search (PIS), based on a hierarchy of information sources.
- Defines how to model such information.
- Defines how to characterize such model, in order for the Revit template (Annex B) to classify it automatically.

4.5.1 Information to find

Information to model in each chapter is:

- 1 File setting: general guidelines that organize spaces: structural axis and levels.
- 2 General modelling: elements of the Worksets Substructure, Shell, Interiors.
- 3 Services modelling: elements of the Worksets Conveying, Plumbing, HVAC, Electrical.

The guide explains all the parameters that should be characterized in each chapter, which were the outcome of chapter 4.2.3 of this document, and are detailed in tables XX – XXIX In the Revit template (Annex B), these parameters are found in the Schedules (tables) that organize the data of the model, this schedules complete automatically as the user introduces data in the 3D model.

4.5.2 How to find such information: PIS

In order to find required information, the Procedure of Information Search proposes to rely on:

- 1st Revit model of the building. If it's not available:
- 2nd As built project. If it's not available:
- 3rd Executive project. If it's not available:
- 4th Maintenance plan. If it's not available:
- 5 th In situ measurements: the guide provides several techniques based on the data to find.

4.5.3 How to model such information

Once found required information, the guide explains how to model it, so the Revit template (Annex B) classifies it automatically. This process relies in a file called *Shared Parameters.txt*. This file holds all the parameters that the Revit schedules classify. The elements of the building (doors, windows, fan-coils, etc.) have been characterized based on the parameters of this file, so when they are introduced in the model of the building, the Revit schedules recognize such parameters and classify them.

The consistency between the Revit family of a certain element, and the schedule that classifies it, lies in the *Shared Parameters.txt* file.

In order to ensure this consistency, when the modeller creates/downloads a new Revit family of a certain equipment, he/she must characterize such Revit family with the parameters indicated. The guide explains the Revit instructions to do so.

4.5.4 How to evaluate such information: LOR test

Once all the elements of each chapter have been modelled, the Inventory Model is ready for use and the modeller can implement the LOR test (chapter 4). To do so, the modeller should export all the Revit schedules as *.txt* files, and save them as Excel tables. These tables contain all the data that characterizes the elements of the model.

This tables will also contain data which was useful to identify the elements in the Revit model (as the Family of the item or its Assembly Code), but it makes no sense to evaluate the realism of such data, as it is not real, is virtual data which was useful to organize the Revit model. So, these 2 parameters should be deleted, so the Realism of the model is evaluated based on data susceptible of being real.

From this point on, the guide explains the process to applicate the LOR test, which was developed in chapter 4.4 of this document.

4.6 Conclussions

Main improvements achieved in this guide are the following:

- Centralize information that is spread in different sources. As Revit allow to organize the data of the elements by schedules, there is no need to rely on excel tables as an intermediate step between gathering of information and modelling, the modelling process inside Revit allow to define each of this properties inside the model of the building.

- Classification System: organize the elements of the model according to a classification system readable by BIM software, as Revit allows the characterization of the elements according to any of the categories and sub-categories of UniFormat II.

- Specify data requirements based on its relevance for FM purposes: LOD/LOI.
  The properties to model in this guide stablish both geometric and non-geometric requirements, therefore contemplate data needed by facility managers, in addition to the geometrical definition of each LOD level.

- Provides a Revit template (Annex B) configured to automatically classify this data.

- Addresses the modelling of Revit families, in order for them to be complete and readable in the Revit template (Annex B).

- Proposes a method of evaluation of the Level of Realism, based on the Quality of information and the Relevance of it.

5. CASE STUDY

The practical implementation of the guide (Annex A), has been carried out in the Gaia building, at UPC Campus Terrasa.

5.1 Building description

The research Gaia building is located in the UPC campus of Terrasa, is a 6 storey building, composed by 1 parquing, the main ground floor and 4 upper floor. The building was built in 2007, and refurbished in 2015.

It is composed by reinforced concrete structure, with containing walls and slab underground, and frames organized by a unidirectional schema on the upper floors. The typical façade is composed by an interior ceramic brick layer, with metallic panels of Alucobond on the outside, plus polyurethane foam as thermal isolation. The roofing is accessible in maintenance areas, with self-filtering porous concrete, and non-accessible in the rest of the cases, with inverted roofing with gravel.

5.1.1 Previous information of the building

This case of study was developed based on the following resources of information:

- Executive project of the building as designed in 2007:
  - Constructive memory:
    - Structure
    - Primary closures
    - Primary partitions and interior closures
    - Exterior finishes
    - Secondary closures
    - Secondary partitions and secondary interior closures
    - Services:
      - Sanitation
      - Plumbing
      - Electric
      - Gas
      - HVAC
      - Telecommunications
      - Fire protection
      - Security
  - Measurements and budget

- Basic project of the building as designed in 2015:
  - Floor plan of all the 6 floors.

- Maintenance plan of the building as designed in 2015:
  - Manual of use and maintenance
    - Site conditioning
    - Foundations
    - Structure
    - Shell
    - Services
    - Isolation and waterproofing
    - Roofs
    - Finishes
    - Signs and equipment
    - Interior urbanization

  - Inventory of the existing equipment of the services.

5.2 Modelling process of Gaia building following the Guide for modelling (Annex A).

This chapter implements the steps of Annex A: Guide to model an existing building in BIM.

5.2.1 File setting

The steps followed to develop the model of the building were the following:

1. Open Revit template file: Annex B. This Revit file has been specially configured to model, characterise and classify the elements of the building according to the guidelines of this research.

2. In tab Collaborate, click on Worksets: Select all Worksets and click on Editable. Click OK

3. Select Workset: Shared Levels and Grids.

4. Go to default plan view.

5. Follow the PIS hierarchy to rely on DWG or PDF drawings of your building:

5.b.b.a I had DWG Executive project of Gaia building

As the CAD drawings were not equally placed in respect to the origin of coordinates, I adjusted their position placing the origin of coordinates in the upper left corner of the elevators hole, which is a point equally placed in all floors. Every DWG had equal units (m, m^2, m^3, kg)

After that I imported one of them at TAB: Insert, Import CAD

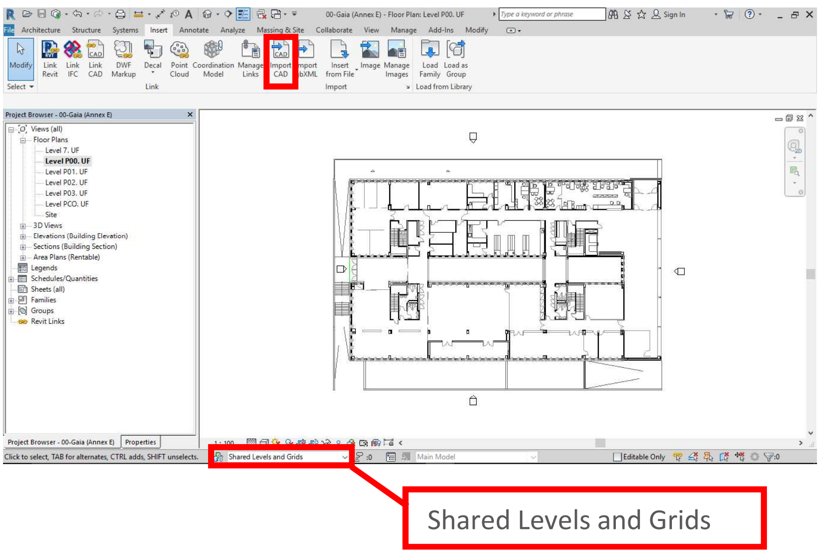


Figure 19. Import of the CAD file.

6. Model the floors of your building:
In elevation view were created as many levels as the floors of the building to model (figure 20):

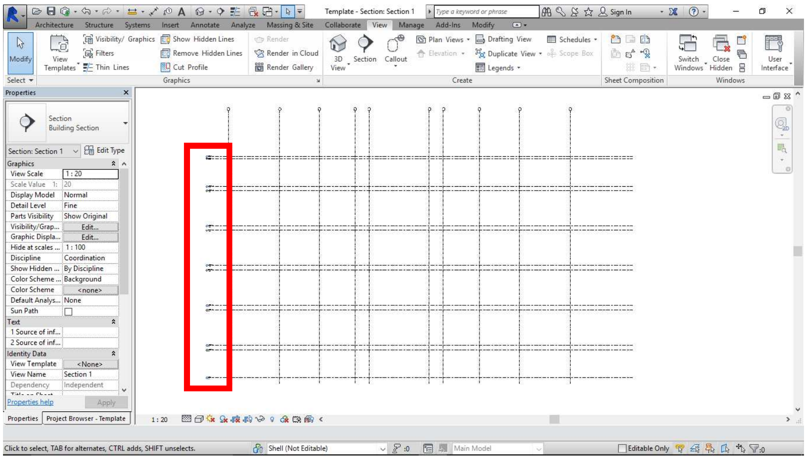


Figure 20. Modelling of the elevation levels

7. Create a floor plan view for each floor.

8. Verify that floor plan views have been successfully created.

9. Model the floors of your building: in this case there is a floor plan grid composed by 10X axis and 6Y axis (figure 21), and 7 levels (figure 20) that define the organization of the structure.

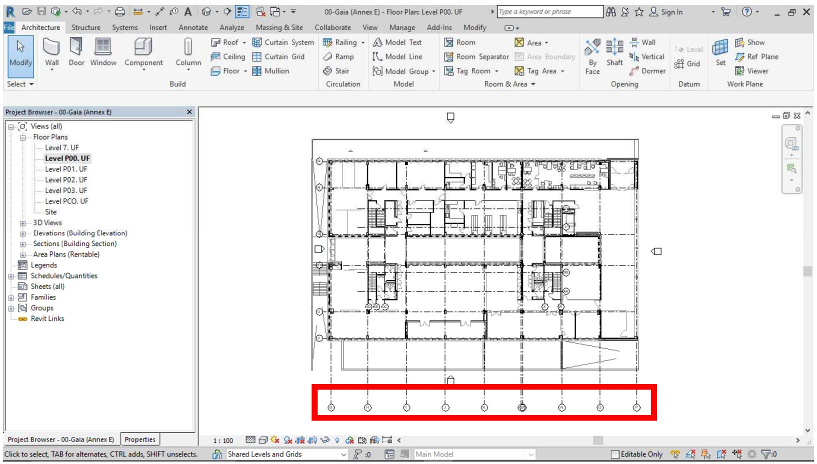


Figure 21. Revit model, floor plan grid.

5.2.2 General modelling of: substructure, shell and interiors

10. Follow the PIS hierarchy to define the geometry of these elements: depending on the element I relied in:

10.b.a Executive project: most part of the general modelling was developed based on the executive project. Refurbished areas of the building were developed based on the Basic project of 2015.

10.b.b.a Maintenance plan.

10.b.b.b In site measurements. They were taken in the cases in which the Executive project was not consistent between sheets.

- Column in the basement, placed near the structural joint: it was missing in all the CAD files and it was indicated in the Executive Project in PDF.

- Evacuation stairs of the entrance: they were placed in different position between floor plan and section, with a difference of 20cm.

11. Use the tools to model the elements in their respective Worksets:
The outcome of this process is attached in the Revit model of Gaia Building (Annex C), and in the document *Sheets*, attached. Figures 22-24 show a view of the model:

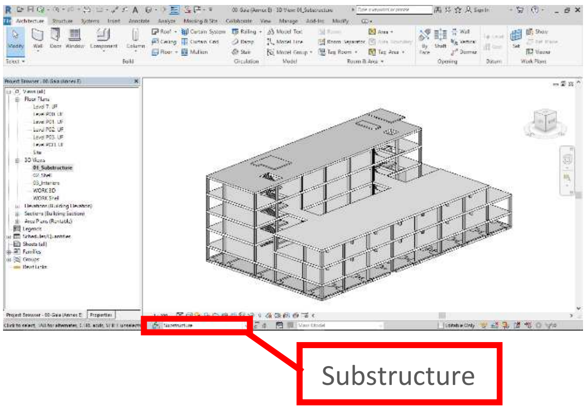


Figure 22. Revit model: Workset Substructure.

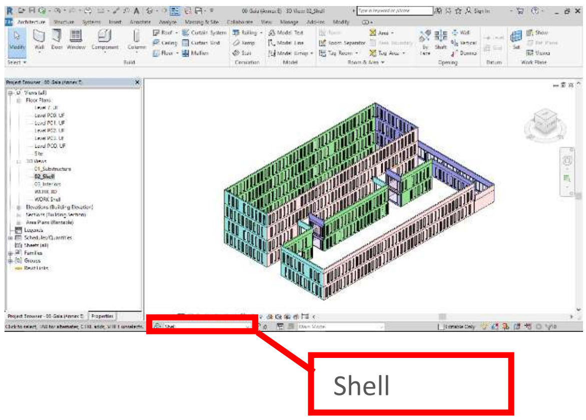


Figure 23. Revit model: Workset Shell.

Workset Interiors:

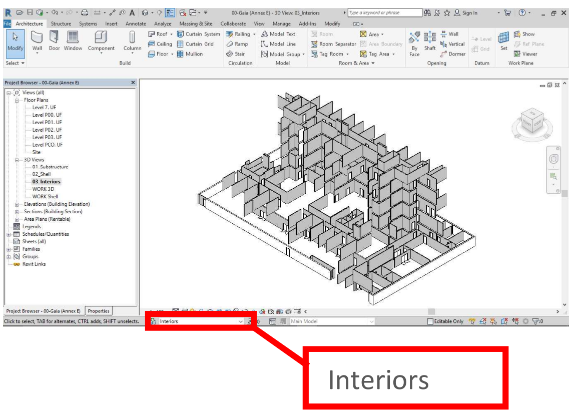


Figure 24. Revit model: Workset Interiors.

12. In each of the schedules, complete the required data of the elements of each Workset.

Annex D shows the outcome schedules of Gaia modelling, which were obtained from the Revit model Annex C. These schedules are exemplified in tables XXXIV and XXXV.

Table XXXIV. Structural Foundation Schedule

01.01 Structural Foundation Schedule							
Count (ud)	Family	Level	Structural Material	Width	Length	Assembly Code	Source of information
8	M_Footing-Rectangular	Level PS.1	Concrete, Cast-in-Place gray	1.50	2.00	A1010	Executive project
16	M_Footing-Rectangular	Level PS.1	Concrete, Cast-in-Place gray	1.50	2.45	A1010	Executive project
12	M_Footing-Rectangular	Level PS.1	Concrete, Cast-in-Place gray	2.00	2.00	A1010	Executive project
24	M_Footing-Rectangular	Level PS.1	Concrete, Cast-in-Place gray	2.45	2.00	A1010	Executive project

Table XXXV. Floor schedule

01.02 Floor Schedule							
Area	Family	Level	Structural Material	Depth	Function	Assembly Code	Source of information
2019 m²	Floor	Level PS.1	Concrete, Cast-in-Place gray	5.0 cm	Interior	B10	Executive project
2005 m²	Floor	Level P00. UF	Concrete, Cast-in-Place gray	47.0 cm	Interior	B1012	Executive project
1745 m²	Floor	Level P01. UF	Concrete, Cast-in-Place gray	47.0 cm	Interior	B1012	Executive project
712 m²	Floor	Level P03. UF	Concrete, Cast-in-Place gray	47.0 cm	Interior	B1012	Executive project
1509 m²	Floor	Level P02. UF	Concrete, Cast-in-Place gray	47.0 cm	Interior	B1012	Executive project

5.2.3 Services modelling: conveying, plumbing, HVAC, fire protection, electrical

13. Follow the PIS hierarchy to define the geometry of these elements: depending on the element I relied in:

13.b.a Executive project: most of the information of the Services modelling was based in the Executive project, specially the budget.

13.b.b.a Maintenance plan: information provided by the executive project was verified in the maintenance plan.

13.b.b.b In site measurements. They were taken in the cases in which Executive project and Maintenance plan were inconsistent:

- Water tanks: in the Executive project were 2 units contemplated in the drawings, the budget and specifications indicated 3 units. Really there are 2 units.

- Boiler: brand and model indicated by the executive project differ from the real one.

14. Use the COMPONENT tool to search the elements to model.

14.a I modelled the equipment of the services in their respective position and Workset. Figure 25 show an example of the graphical outcome of the services modelling, found in Annex C (Revit model of Gaia building).

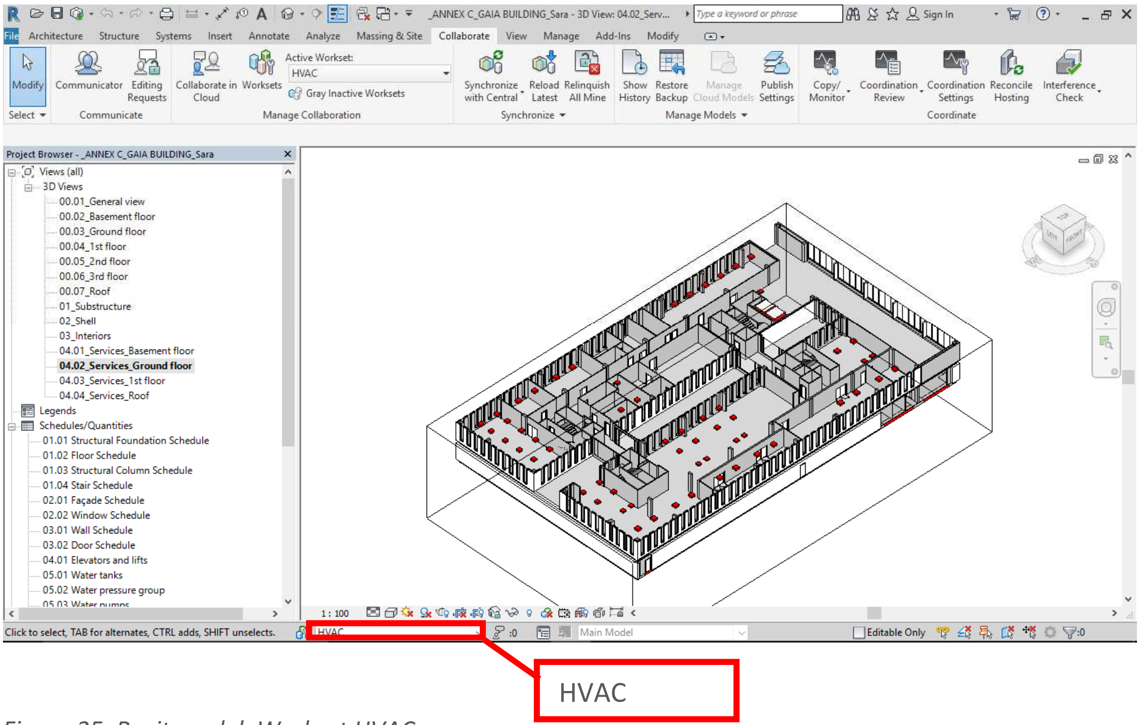


Figure 25. Revit model: Workset HVAC

The Sheets attached to this document show the complete outcome of the Revit model of the case of study.

15. In each of the schedules, complete the required data of the elements of each Workset.

Annex B shows the outcome schedules of Gaia modelling, which hold all the properties required based on the LOI of each category. This schedules are exemplified in tables XXXVI, XXXVII, XXXVIII and XXXIX:

Table XXXVI. Revit model: Schedule elevators and lifts.

04.01 Elevators and lifts									
Count	Family	Level	Brand	Model	Capacity (people)	Speed (m/s)	Dimensions (m)	Assembly Code	Source of information
1	Lift	Level PS.1	KONE	MONOSPACE	8	1	1,5x1,2m	D1010	Executive project
1	Lift 4floors	Level PS.1	KONE	MONOSPACE	8	1	1,5x2,6m	D1010	Executive project

Table XXXVII. Revit model: Schedule water tanks.

05.01 Water tanks										
Count	Family	Level	Brand	Model	Volume (l)	Acc. Temp.	Distrib. Temp.	Dim. (m)	Assembly Code	Source of information
1	Water tank	Level PS.1	REMOSA		5000	60 °C	50 °C	1.15	D201010	Executive project
1	Water tank	Level PS.1	REMOSA		5000	60 °C	50 °C	1.15	D201010	Executive project

Table XXXVIII. Revit model: Schedule Cooling generating systems, heat pumps.

06.02 Cooling generating systems, heat pumps										
Count	Family	Level	Brand	Model	Heating power (kWc)	Cooling power (kWc)	Power supply	Type	Assembly Code	Source of information
1	Heat pump	Level PCO. UF	CIAT	IWA-315	70.4	64	26000 m3/h	Heat pump	D303020	Executive project
1	Heat pump	Level PCO. UF	CIAT	IWA-315	70.4	64	26000 m3/h	Heat pump	D303020	Executive project

Table XXXIX. Revit model: Schedule Cooling generating systems, chiller.

06.03 Cooling generating systems, chiller								
Count	Family	Level	Brand	Model	Electric power (kWe)	Cooling power (kWc)	Assembly Code	Source of information
1	Chiller	Level PCO. UF	AIRLAN	NSB2802E	207	574	D303030	Executive project
1	Chiller	Level PCO. UF	AIRLAN	NSB2802E	207	574	D303030	Executive project

5.3 Evaluation of the Level of Realism

16. Once the properties required for each element have been completed in the Revit schedules, the LOR test was developed to verify the realism of the model.

Level of Realism = Parameter's Quality x Parameter's Relevance

16.1 Export each schedule to excel, as indicated in the Guide for modelling (Annex A)

16.2 Join them into one unique excel of several sheets.

16.3 In each sheet, delete columns that indicate Family and Assembly Code, as these are virtual data, not susceptible of being real.

16.4 Substitute the value of each parameter by such Parameter's Quality ($PQ_{individual}$), following this criteria:

- 1.00 point: In-place verified data
- 0.90 points: As built document
- 0.75 points: Executive project and Maintenance plan
- 0.50 points: Basic project

16.5 Multiply $PQ_{individual}$ by the number of unit:

Column 1 (count or area) x $PQ_{individual}$

Annex E holds the whole development of the LOR test for every schedule of the case of study, this step it is exemplified in tables XL, XLI, XLII.

Table XL. LOR test, case of study: Element's $PQ_{individual}$: structural foundation

	01.01 Structural Foundation Schedule				
	Count (ud)	Level	Structural Material	Width	Length
$PQ_{individual}$	8	0,75 * 8= 6	0,75 * 8= 6	0,75 * 8= 6	0,75 * 8= 6
	16	0,75 * 16= 12	0,75 * 16= 12	0,75 * 16= 12	0,75 * 16= 12
	12	0,75 * 12= 9	0,75 * 12= 9	0,75 * 12= 9	0,75 * 12= 9
	24	0,75 * 24= 18	0,75 * 24= 18	0,75 * 24= 18	0,75 * 24= 18

0,75
PQ Executive project

Table XLI. LOR test, case of study: Element's $PQ_{individual}$: Elevators and lifts.

	04.01 Elevators and lifts						
	Count	Level	Brand	Model	Capacity (nº people)	Speed (m/s)	Dimensions (m)
$PQ_{individual}$	1	0,75	0,75	0,75	0,75	0,75	0,75
	1	0,75	0,75	0,75	0,75	0,75	0,75

0,75
PQ Executive project

Table XLII. LOR test, case of study: Parameter's PQ: Cooling generating systems, chiller.

	06.03 Cooling generating systems, chiller						
	Count	Level	Brand	Model	Electric power (kWe)	Cooling power (kWc)	
$PQ_{individual}$	1	1	0,75	0,75	0,75	0,75	1 PQ In-place verified data
	1	1	0,75	0,75	0,75	0,75	0,75 PQ Executive project

16.6 Below each sheet, add 4 rows, and compute in each of them:

PQ	Average of $PQ_{individual}$ of each parameter
R^n_1	Based on table XXXII.
$LOR_{individual}$	PQ x R^n_1
$LOR_{element}$	Average of $LOR_{individual}$ of all columns

The Parameter's Relevance R1 was stablished according to table XXXI of this document.

Annex E holds the whole development of the LOR test for every element of the case of study, this step it is exemplified in tables XLIII, XLIV, XLV.

Table XLIII. LOR test, case of study: LOR element: Structural foundation.

	01.01 Structural Foundation Schedule				
	Count (ud)	Level	Structural Material	Width	Length
$PQ_{individual}$	8	6	6	6	6
	16	12	12	12	12
	12	9	9	9	9
	24	18	18	18	18
PQ		0,75	0,75	0,75	0,75
R^n_1		1	0,8	0,5	0,5
$LOR_{element}$		0,75	0,6	0,375	0,375
LOR		0,75			

Table XLIV. LOR test, case of study: LOR element: Elevators and lifts.

	04.01 Elevators and lifts						
	Count	Level	Brand	Model	Capacity (nº people)	Speed (m/s)	Dimensions (m)
$PQ_{individual}$	1	0,75	0,75	0,75	0,75	0,75	0,75
	1	0,75	0,75	0,75	0,75	0,75	0,75
PQ		0,75	0,75	0,75	0,75	0,75	0,75
R^n_1		1	1	1	1	1	1
$LOR_{element}$		0,75	0,75	0,75	0,75	0,75	0,75
LOR		0,75					

Table XLV. LOR test, case of study: LOR element: Cooling generating systems, chiller.

	06.03 Cooling generating systems, chiller					
	Count	Level	Brand	Model	Electric power (kWe)	Cooling power (kWc)
$PQ_{individual}$	1	1	0,75	0,75	0,75	0,75
	1	1	0,75	0,75	0,75	0,75
PQ		1	0,75	0,75	0,75	0,75
Rn1		1	1	1	1	1
$LOR_{element}$		1	0,75	0,75	0,75	0,75
LOR		0,81				

16.7 Obtained the LOR of each element, compute the LOR of each Workset, by computing: summatory ($LOR_{element}$ x R^n_2)= LORworkset (Table XLVI). As indicated in the guide, R^n_2 was based on table XXXII of this document.

Table XLVI. LOR test: case of study: LOR Worksets

WORKSET	Element	LORelement	R^n_2	LORworkset
01. SUBSTRUCTURE	01.01 Structural Foundation	75,00%	25%	77,78%
	01.02 Floor	75,00%	25%	
	01.03 Structural Column	75,00%	25%	
	01.04 Stair	86,11%	25%	
02. SHELL	02.01 Façade (1518 m^2)	93,75%	1518/ (1518+607)= 70%	89,40%
	02.02 Window (607 m^2)	81,00%	607/ (1518+607)= 30%	
03. INTERIORS	03.01 Wall	75,00%	50%	65,34%
	03.02 Door	55,68%	50%	
04. CONVEYING	04.01 Elevators and lifts	75,00%	100%	75,00%
05. PLUMBING	05.01 Water tanks	75,00%	60%	78,33%
	05.02 Water pressure group	83,33%	40%	
06. HVAC	06.01 Cooling generating systems, boiler	87,50%	30%	75,21%
	06.02 Cooling generating systems, heat pumps	81,25%	10%	
	06.03 Cooling generating systems, chiller	81,25%	20%	
	06.04 Terminal and Package units, air handling units	62,50%	20%	
	06.05 Terminal and package units, fan-coils	62,50%	10%	
	06.06 Terminal and Package units, splits	58,33%	10%	
07. ELECTRICAL	07.01 Electrical Service/Distribution, electric panelboard	62,50%	60%	43,75%
	07.02 Electrical Service/Distribution, distributing panelboard	62,50%	40%	

Obtained the LOR of each Workset, is computed the LOR of the overall model (table XLVII), computing: LORmodel= summatory (LORworkset x $R^n{}_3$). $R^n{}_3$ is indicated in table XXXIII of this document, and figures also in the guide.

Table XLVII.LOR test: case of study: LOR Model

WORKSET	LORworkset	$R^n{}_3$	LORmodel
SUBSTRUCTURE	77,78%	10%	71,48%
SHELL	84,38%	15%	
INTERIORS	64,39%	10%	
CONVEYING	75,00%	15%	
PLUMBING	78,33%	15%	
HVAC	75,21%	20%	
ELECTRICAL	43,75%	15%	

Most LORelement approximate to 75% as most of the information was taken from the executive project and the maintenance plan. The Shell LOR is slightly higher as the Orientation parameter of façades and windows has been considered as a parameter of Quality 1, as it is information verified on the site. Regarding the HVAC services, chapters 06.04-06.06 have a lower LOR, as the Level of Information required the electric power of several equipment, which was not found in the executive project, nor in the inventory of existing equipment. The Electrical services have a low LOR, chapter 07.01 required the electric power of the 3 electric panelboards, and the executive project provides only the electric power of one electric panelbard, which was refurbished in 2015, posteriorly to the installation of the other 2. Chapter 07.02 has also a low LOR, as the dimensions of the distributing panelboards are only obtainable measuring on the site.

5.3 Comments on the development of the Revit template file

The Revit template file addresses the characterization and classification of the information required, both in the Revit families of each element of the building, as in the Revit model of the building. To achieve this task, in this model relies in a file called *Shared parameters.txt*, this file holds the parameters which characterize the Revit families to model, which the Revit schedules classify. This file ensures the consistency, in terms of computer language, between the data characterized in the families and the data classified in the model of the building. But the *Shared parameters.txt* file has proved to have one main handicap, which is a lack of adaptability in case a parameter changes. If a parameter is created to contain numerical information, it is not possible to modify it to hold semantical information; if it is created as part of a group of parameters inside the *Shared parameters.txt*, it is not possible to change the group it belongs to; any modification of a parameter requires deleting it, creating a new one and characterizing it, both in the *Shared parameters.txt* file, in the families it characterizes, and in the Revit schedules it belongs to.

6. CONCLUSSIONS

6.1 Outcome

The outcome of this research is a guide that addresses the modelling of an existing facility in BIM. Based on different sources of information, which were not consistent between them, BIM allowed to centralize information into one unique and reliable model.

The starting point of this guide was based on the work "Study of the modelling process in BIM of an existing building in Campus Terrasa" (Seuma Areñas 2016). Main improvements are:

- Classification System: in order to organize the elements of the building inside the model, UniFormat II was found as the most suitable classification system, based on its scope, ease of use and integration in BIM software.

- Data requirements based on their relevance for FM purposes: this guide addresses the challenge of defining which data should be modelled, according with the needs of facility managers. This requirements are stablished by means of the Level of Development and Level of Information, embracing both graphical and non-graphical information.

- Centralize information: this guide provides a Revit template configured to: (1) organize the elements of the building according to the categories of UniFormat II, (2) specify data to characterize in each category, according to its LOD/LOI, (3) characterize information directly in the Revit file, without intermediate software.

- Process of modelling: this guide proposes a sequence of modelling that: (1) deals with spread and incoherent sources of information: it provides a criteria to address this issue based on a hierarchy of reliability, (2) deals with the lack of information: it proposes several techniques to find required information, (3) evaluates the level of realism of the model.

- Evaluation of the Level of Realism: based on the sources of information, this guide proposes a test to evaluate the LOR, based on the Quality of information and its Relevance.

The result of this process is an Inventory Model of the building, a centralized, updated and coherent source of information, in which facility management can rely. This guide was implemented in a practical case: Gaia building, at UPC Campus Terrasa.

6.2 Discussion points

The classification system was a point of discussion. Although UniFormat II was finally chosen, OCCS was strongly considered due to several advantages:

- OmniClass Number lies in the core of the equipment's model, while the Assembly Code is a parameter characterized from the general model. To characterize from the core of the equipment's model would have been useful because:
  - The models of equipment provided by the guide to the user would be already characterized, therefore automatically classified. By using Assembly Code, this task must be performed by the user, in the model of the building. This implicates time, effort, and the risk of a mistaken characterization.

- OCCS allows to specify more precisely the type of equipment, while the most precise subcategory of UniFormat II is still generic.

Nevertheless, OCCS presents a disadvantage that disables it as a suitable classification system, which is the current incapability of Revit to characterize according to most of OCCS categories. Up to date Revit only allows to characterize an OCCS Number according to some elements of OCCS-Table 23, but it in fact allows to characterize the Assembly Code according to all categories of UniFormat II. The characterization code (whether OCCS Number or Assembly Code) is the basis for classifying and characterizing elements, it is the filter that Revit Schedules use to define which objects belong in each of them, once the characterization code is introduced in an equipment, that equipment figures in its corresponding schedule, then is possible to characterize it. The lack of a characterization code recognizable by Revit, disables this process, so OCCS is not an option.

If further improvement of this software allowed to characterize according to all elements of OCCS-Table 21, OCCS would be the best classification system.

6.3 Future steps

Further research lines are:

- This research applies to educational buildings, but the modelling of residential buildings, single houses or hospitals is out of scope. To extend the applicability of this guide, one line of research is the definition of the services to model in those types of buildings, as they differ very much from the services to model of an educational facility.

- The scope of this research finishes when the Inventory Model is completed, but does not embrace the possible relation that this Revit Model could have with other FM software. In this line, main challenges yet to solve are:
  . How to produce and characterize Revit families, in order for other software to identify them as elements of a certain condition.
  . How to transfer such model from Revit to other FM software (as Archibus), ¿Is .ifc the only available format?
  . In case some information was lost along the transfer process, due to a lack of full interoperability ¿which information would remain? In order to invest effectively modelling time.

- Revit is capable of connecting with other software by means of input and output data, this means that is possible to use a Revit model to feed another software, but also to feed a Revit model based on other software data. Potential benefits of the second process could be:
  . A Revit model fed by a software of deflections monitoring, which updates the model based on the real deformations of the building.
  . A Revit model fed by any software that measures, in real time, any certain feature, updating the model based on reality.

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